What Satellites See:
Eyes Above the Skies

Introduction and Background

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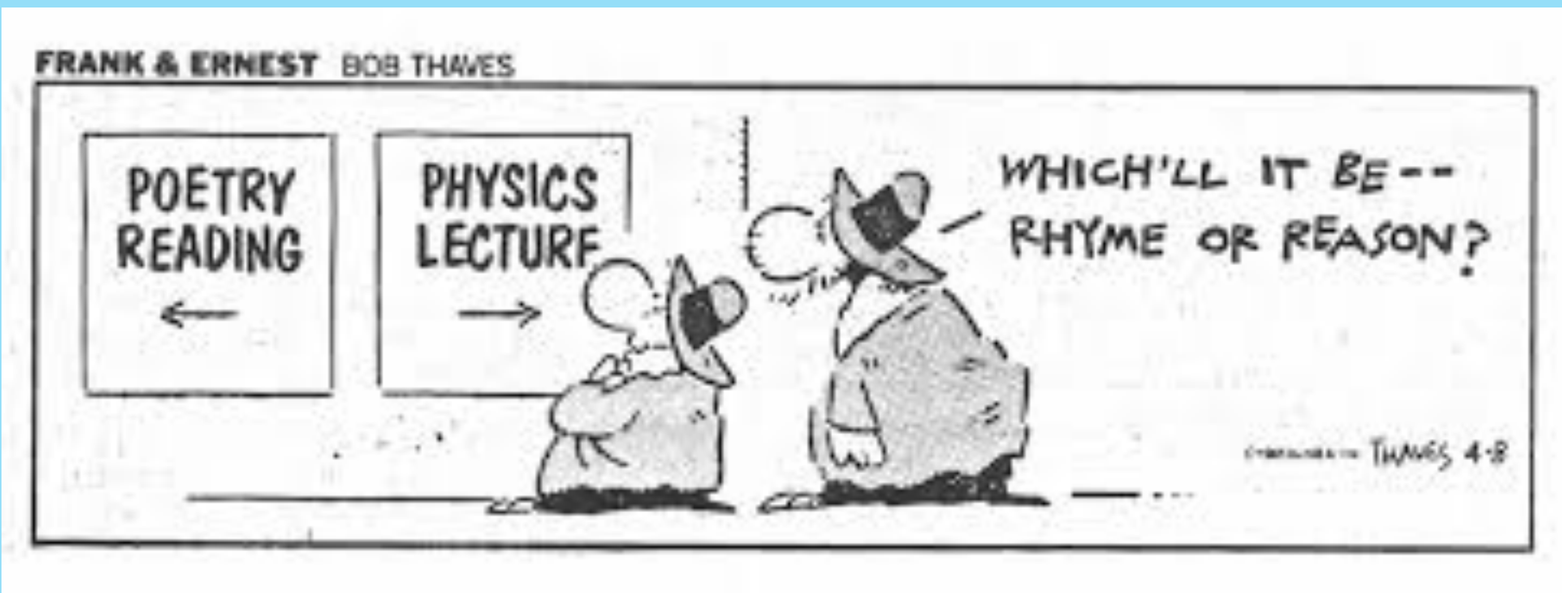
Wind Crest Learners
Academy for Lifelong Learning

"The most remarkable aspect of astronomy is not in the sky, but on the Earth, where a species has developed curiosity to look into the sky and wonder."

R. Kolb, *Blind Watchers of the Sky*

A Personal Retrospective: Ruminations and Reflections on my career at NASA/GSFC



Can you all see this? Anyone colorblind?

A Personal Retrospective: Ruminations and Reflections on my career at NASA/GSFC

Other questions getting to know you later.

What it's about

- It's about the "eyes" above the atmosphere in satellites that allow us to see cosmic rays, X-rays, gamma rays and infra-red radiation (and why these are different but interconnected, and why they are all important - all in layman's terms, no math) from objects in space - black holes, supernovae, pulsars, colliding stars, colliding galaxies, plasmas in space etc.
- It's about stuff that cannot be observed from the Earth's surface – and what they tell us about how these things way beyond human experience work.

Titles considered

- Discoveries of the past 50 years and how we got better and better at it – from crude beginnings to the current powerful observatories in space.
- How the various radiations are “imaged” for us to “see” the objects in the sky, and how we understand them.
- A Half Century of Discoveries in Space: What, How and Why
- Personal reflections of a NASA scientist
- Discoveries from Space: Satellites, Rockets and Balloons

A Debate

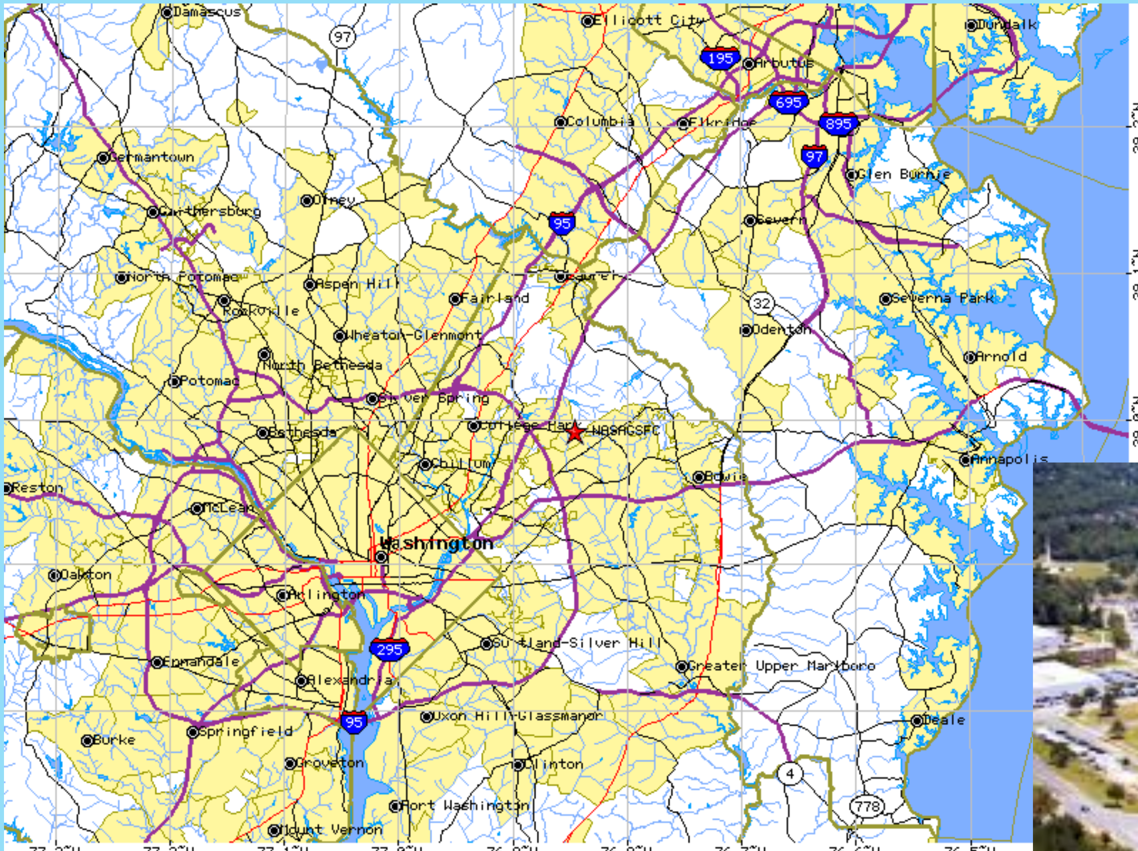
- Karen Long: *Sights from Space: Satellites & Rockets*
- *Woody Emlen: this is not about rockets*
  - "Bombardment from Space"? or "Cosmic Bombardment: Particles from Space"
- JFO: *Woody is almost right; it was all enabled by Rockets so you can keep Rockets if you wish. I did make observations from high altitude balloons (above the sky) and will discuss that research.*

Born and raised in Colorado Springs

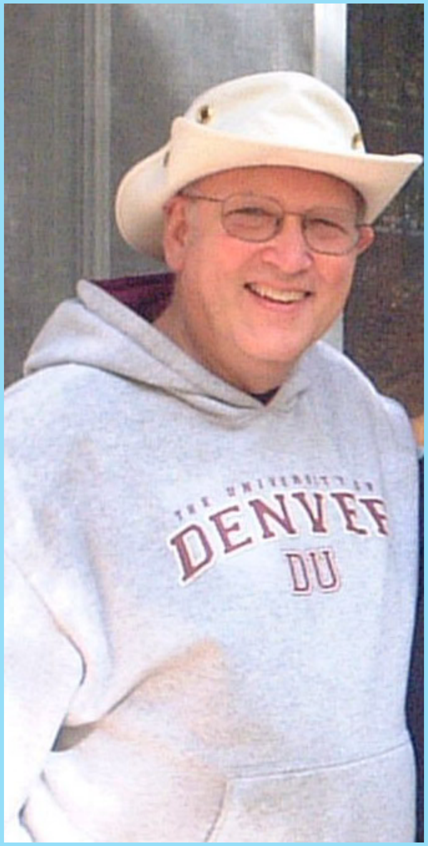
Stanford University '61

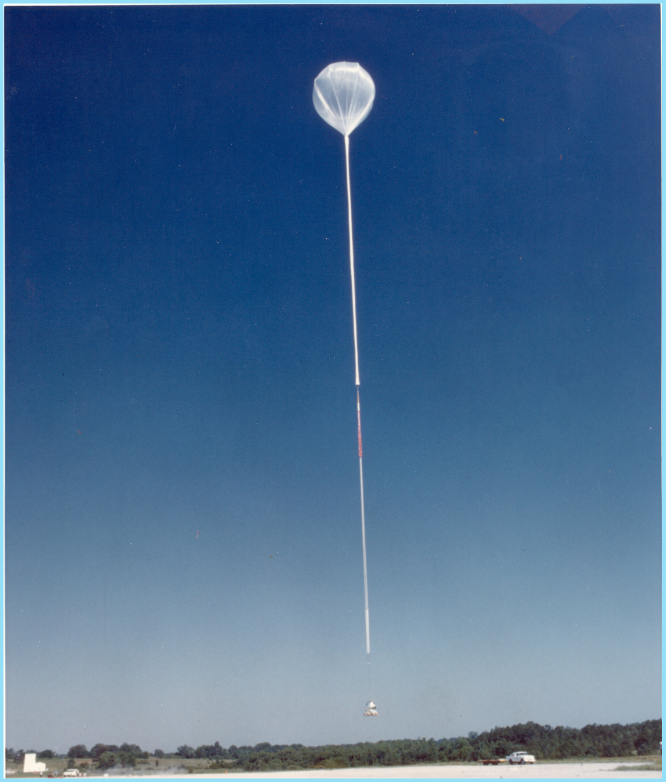
UNIVERSITY OF MINNESOTA

Goddard Space Flight Center



NASA Goddard Space Fight Center
Director of Space Sciences
2000-2004





University of Denver

- Head of Denver Research Institute
  - interested in climate
  - Biggest uncertainty was role of aerosols; tried to start program
  - "If you don't want to do something new and interesting, why have DRI"
  - They called my bluff and offered me and my staff buyouts
- Symposium on the 100th Anniversary of the Discovery of Cosmic Rays with Proceedings
- Course on *Physics of Climate*
- I helped get a plaque at Echo Lake celebrating the important physics research done on the mountain
- Courses on climate and other topics at Academy for Lifelong Learning in SE Denver and environs

Echo Lake

Near this site and at the summit of Mt. Evans, fundamental observations of cosmic rays (energetic atom fragments from space that create subatomic particles in the atmosphere) were made between 1935 and 1960 by physicists Arthur H. Compton, Bruno Rossi, and many others among them faculty at the University of Denver.
These experiments included the first measurement of the lifetime of muons, work that confirmed the time dilation effect predicted by Albert Einstein's theory of relativity.

APS physics

HISTORIC PHYSICS SITE, REGISTER OF HISTORIC SITES
AMERICAN PHYSICAL SOCIETY

Introductions

- Name
- Something interesting about you that even your Academy friends might not know
  - Childhood?
- What you hope to get out of the class
- 7 people each class.

Cosmic rays: What are they, why we care, and the research I did

I need to start with some background

The periodic table
Numbers big and small
The electromagnetic spectrum
Energy scales
Ions and ionization by energetic particles

Dominic Walliman
https://www.youtube.com/watch?v=ARWBdfWpDyc

Please, please, pretty please, stop me if you don’t understand something. There is no such thing as a “stupid question” in this class.

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII	VII	VII	IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 106	107 107	108 108	109 109	110 110								

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Number in the box is the charge;
number of protons in nucleus and number of electrons

Name	Common notation	Math notation	Exponent	Prefix
Million	1000000	10^6	6	Mega (M)
Thousand	1000	10^3	3	kilo (k)
Hundred	100	10^2	2	hecto (h)
Ten	10	10^1	1	Deca (da)
One	1	10^0	0	
One tenth	0.1	10^{-1}	-1	deci (d)
One hundredth	0.01	10^{-2}	-2	centi (c)
One thousandth	0.001	10^{-3}	-3	milli (m)

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One millionth	0.000001	10^{-6}	-6	micro (m)
One billionth	0.000000001	10^{-9}	-9	nano (n)
One trillionth	0.00000000001	10^{-12}	-12	pico (p)
One quadrillionth	0.00000000000001	10^{-15}	-15	femto (f)
One quintillionth	0.00000000000000001	10^{-18}	-18	atto (a)
One sextillionth	0.00000000000000000001	10^{-21}	-21	zepto (z)
One septillionth	0.00000000000000000000001	10^{-24}	-24	yocto (y)
One octillionth	0.00000000000000000000000001	10^{-27}	-27	xonta (x)
One nonillionth	0.00000000000000000000000000001	10^{-30}	-30	weco (w)

Name	Common notation	Math notation	Exponent	Prefix
Septillion	1000000000000000000000000	10^{24}	24	Yotta (Y)
Sextillion	1000000000000000000000	10^{21}	21	Zetta (Z)
Quintillion	1000000000000000000	10^{18}	18	Exa (E)
Quadrillion	1000000000000000	10^{15}	15	Peta (P)
Trillion	1000000000000	10^{12}	12	Tera (T)
Billion	1000000000	10^{9}	9	Giga (G)
Million	1000000	10^{6}	6	Mega (M)
Thousand	1000	10^{3}	3	kilo (k)
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Name	Common notation	Math notation	Exponent	Prefix
Googolplex		$10^{googol}=(10^{10})^{100}$		
Googol		10^{100}	100	
Nonillion	1000000000000000000000000000000	10^{30}	30	
Octillion	1000000000000000000000000000	10^{27}	27	
Septillion	1000000000000000000000000	10^{24}	24	Yotta (Y)
Sextillion	1000000000000000000000	10^{21}	21	Zetta (Z)
Quintillion	1000000000000000000	10^{18}	18	Exa (E)
Quadrillion	1000000000000000	10^{15}	15	Peta (P)
Trillion	1000000000000	10^{12}	12	Tera (T)
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Million	1000000	10^{6}	6	Mega (M)
Thousand	1000	10^{3}	3	kilo (k)
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Ten	10	10^{1}	1	Deca (da)
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One nonillionth	0.00000000000000000000000000001	10^{-30}	-30	weco (w)

The notation can be extended to really big numbers,

but we don't have names for them. We just use math notation.

	$10^{googol}=(10^{10})^{100}$		
	10^{100}	100	
1000000000000000000000000000000	10^{30}	30	
1000000000000000000000000000	10^{27}	27	
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1	10^{0}	0	
0.1	10^{-1}	-1	deci (d)
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0.001	10^{-3}	-3	milli (m)
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0.000000000000000001	10^{-18}	-18	atto (a)
0.000000000000000000001	10^{-21}	-21	zepto (z)
0.000000000000000000000001	10^{-24}	-24	yocto (y)
0.000000000000000000000000001	10^{-27}	-27	xonta (x)
0.000000000000000000000000000001	10^{-30}	-30	weco (w)

The notation can be extended to really small numbers, Powers of ten videos

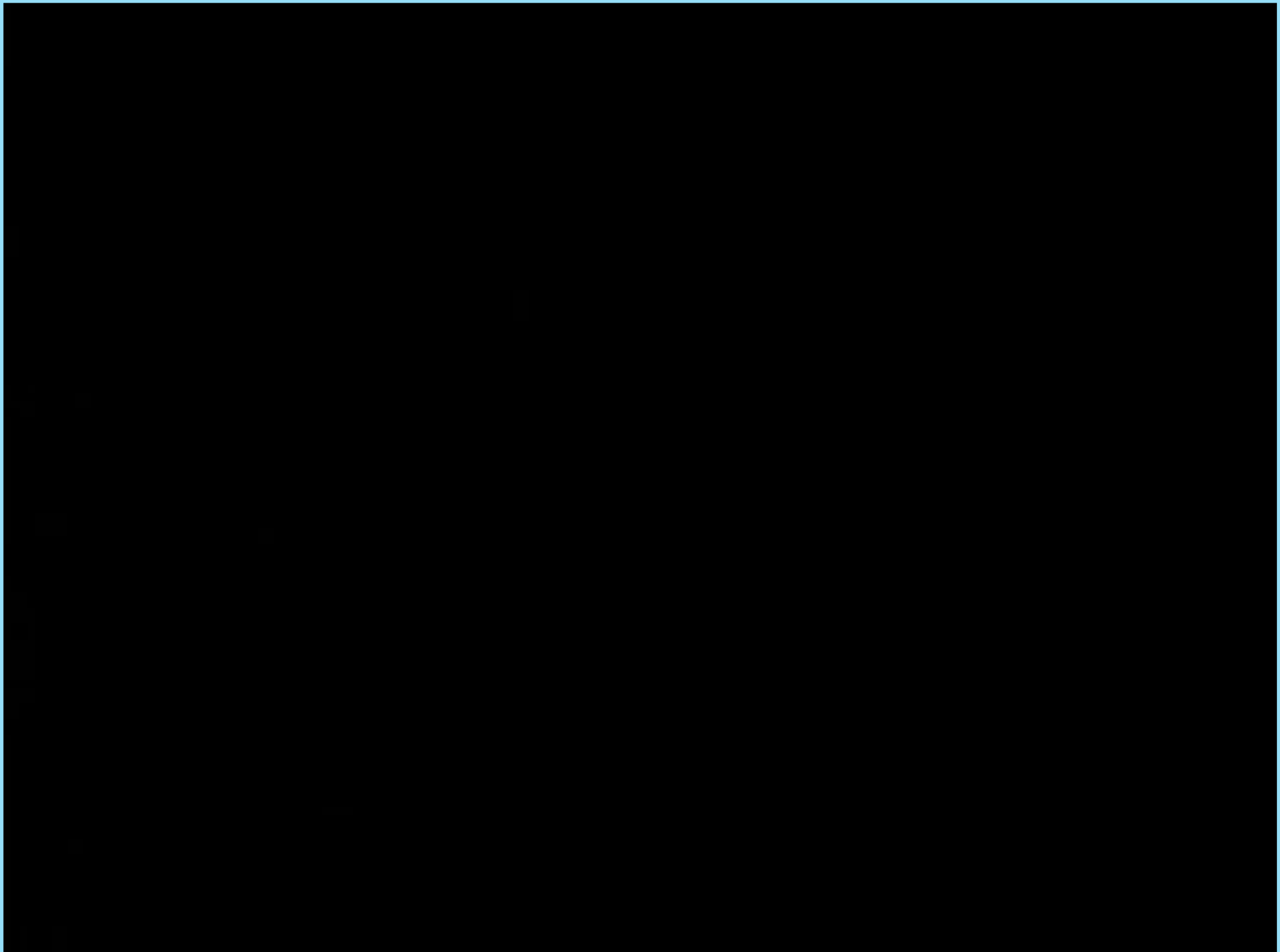
Video 1 https://lesleybiology1.wordpress.com/2018/09/18/in-class-sept-21-powers-o

https://www.bing.com/videos/search?q=Powers+of+Ten+Science&&view=d

Smallest known length: Planck length: 1.6×10^{-35} m
Size of Observable Universe: 13.798 billion light years = 8.8×10^{26} m

So 35+26 = 61 orders of magnitude in size from the smallest thing we think we understand to the largest we can observe.

Now lets have a detour to talk about energy and what it is.



Back to the vastness of space

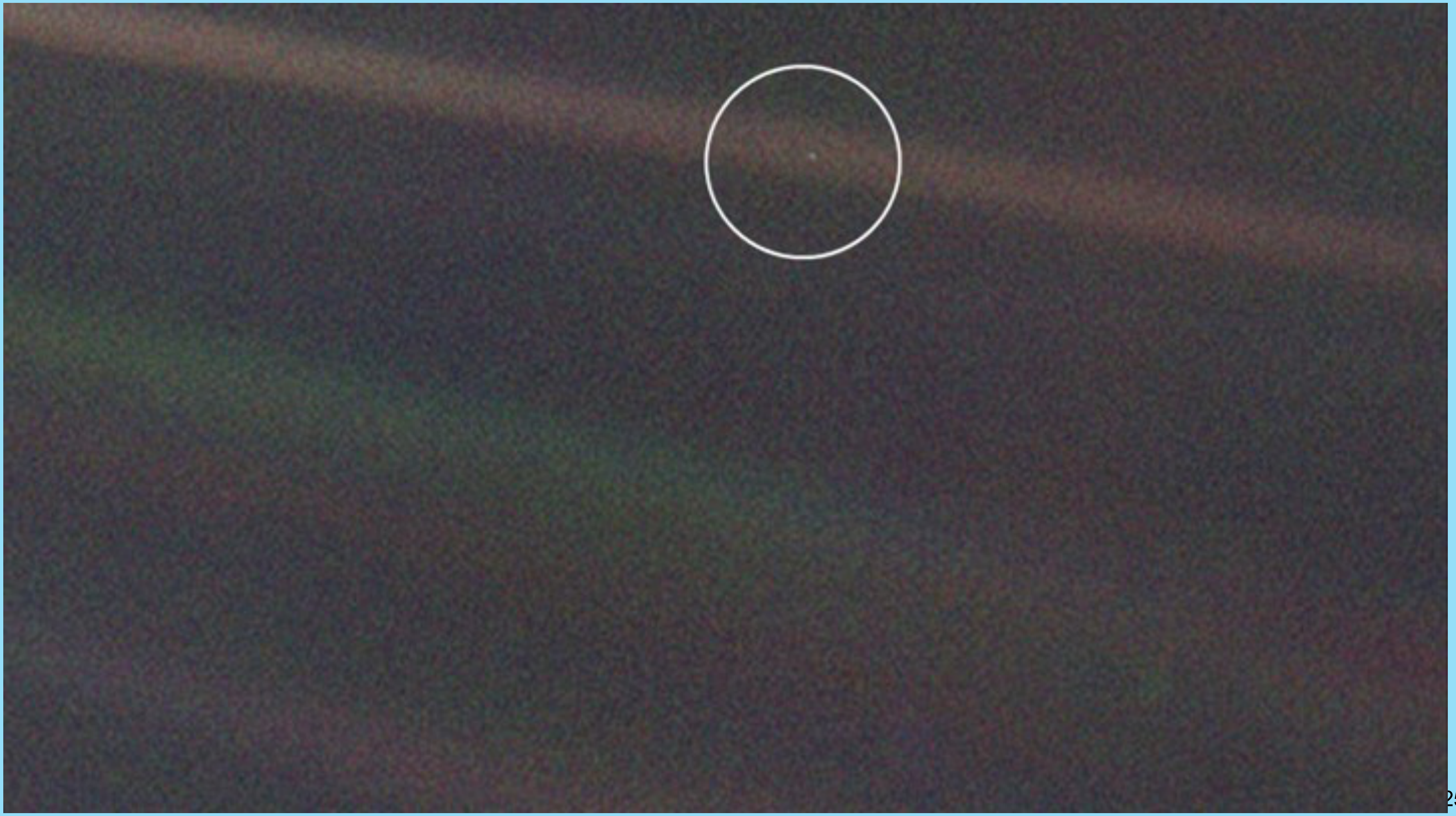
“Earthrise” photo of Earth from the moon

From the moon, Earth would have “phases” of illumination like those of the moon as seen from Earth.

Earth and moon from Mars

Back to the vastness of space

Voyager photo of Earth from just beyond Jupiter



How far away are they

- Moon – 238,900 mi
- Sun - 93 million miles (we call this 1 AU)
  - AU = Astronomical Unit
  - 0.98 – 1.01 AU – slightly elliptical
- Mars – 34 million miles (closest possible) to 250 million miles (furthest possible)
  - Orbit 1.52 AU
- Jupiter – 365 million miles (at closest)
  - 365+365+2x93 = 914 million at furthest
    - Orbit 5.2 AU
- End of heliosphere is about 120 AU=11 trillion miles = 11 x 10^{12} miles =

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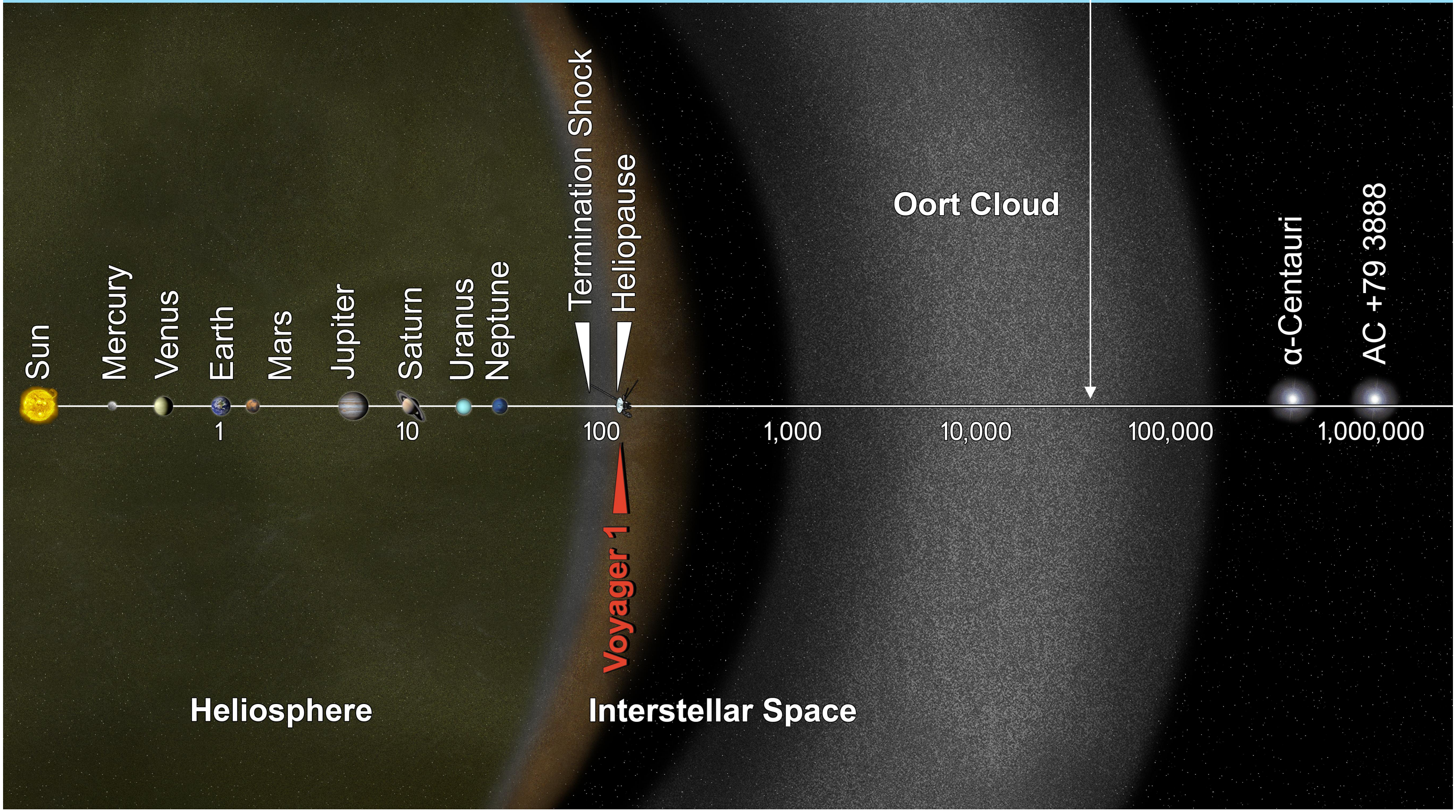
  to 250 million miles (furthest possible)
  - Orbit 1.52 AU
- Jupiter – 365 million miles (at closest)
  - 93 million miles from the sun
  - 365+365+2x93 = 914 million at furthest
    - Orbit 5.2 AU
- End of heliosphere is about 120 AU=11 trillion miles = 11 x 10^{12} miles =

Distances in AU - note log (x10) scale

1 light year = 63241 AU



Size of Milky Way – 100 billion (10^{11}) stars

100,000 (10^5) light years across
(but hard to define an edge)

Andromeda – 2.54 million light years away – & it is the closest galaxy

Stars in the Universe

- Stars in a typical galaxy – 100 billion – 10^{11}
- Galaxies – 2 trillion - 2×10^{12}
- So the answer is

$$2 \times 10^{12} \times 10^{11} = 2 \times 10^{(12+11)} = 2 \times 10^{23}$$

This is close to Avagadro's number, 6×10^{23}

– the number of atoms in a mole of a substance

Note there are lots of different masses of atoms.

Just think of it as 1 gram of water about a sugar cube of water.

Incidentally, you have about 100 billion – 10^{11} – neurons in your brain.

What is energy anyway

- For our later discussions, we need to have some idea what energy is.

- Digression About Energy

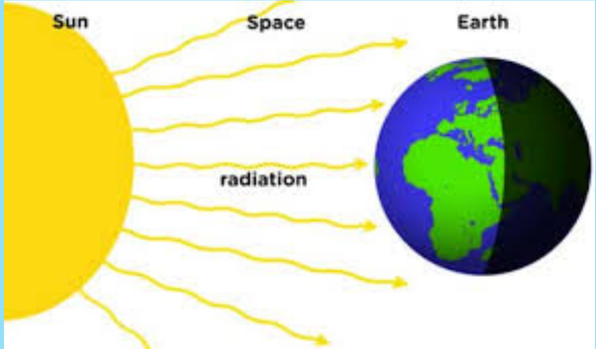
- https://www.youtube.com/watch?v=jCrOtF7T4HE

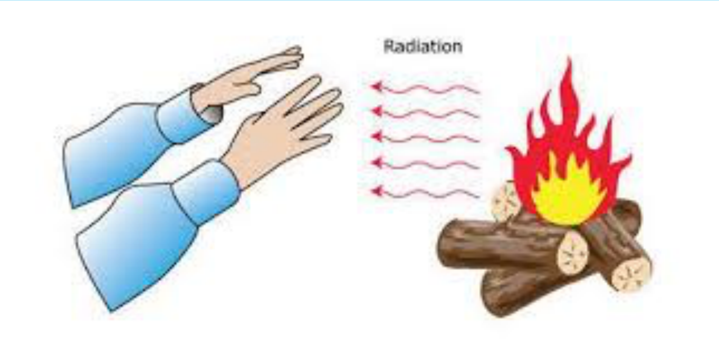
What is a photon?

- A bundle of energy
  - Has no mass
  - Moves at the speed of light
- Photons act like particles
  - It has momentum; photons can hit one another and particles
  - Momentum is the tendency of an object to keep moving once it is in motion (linear and rotational).
  - https://www.youtube.com/watch?v=2htckwDkugI
- The energy is quantized
  - Quantization is the concept that a physical quantity can have only certain discrete values.
- We like to count photons one by one
  - When there are lots of them we can't distinguish individuals.

What is a photon?

- Remove hot object from the oven. The heat is because the molecules in the object are moving. The hotter the object, the more the atoms are moving.
- Set on table. It cools by sending out photons at the frequency of the motion of the atoms.
- Radiation transfers heat. Radiation is a flux of photons.

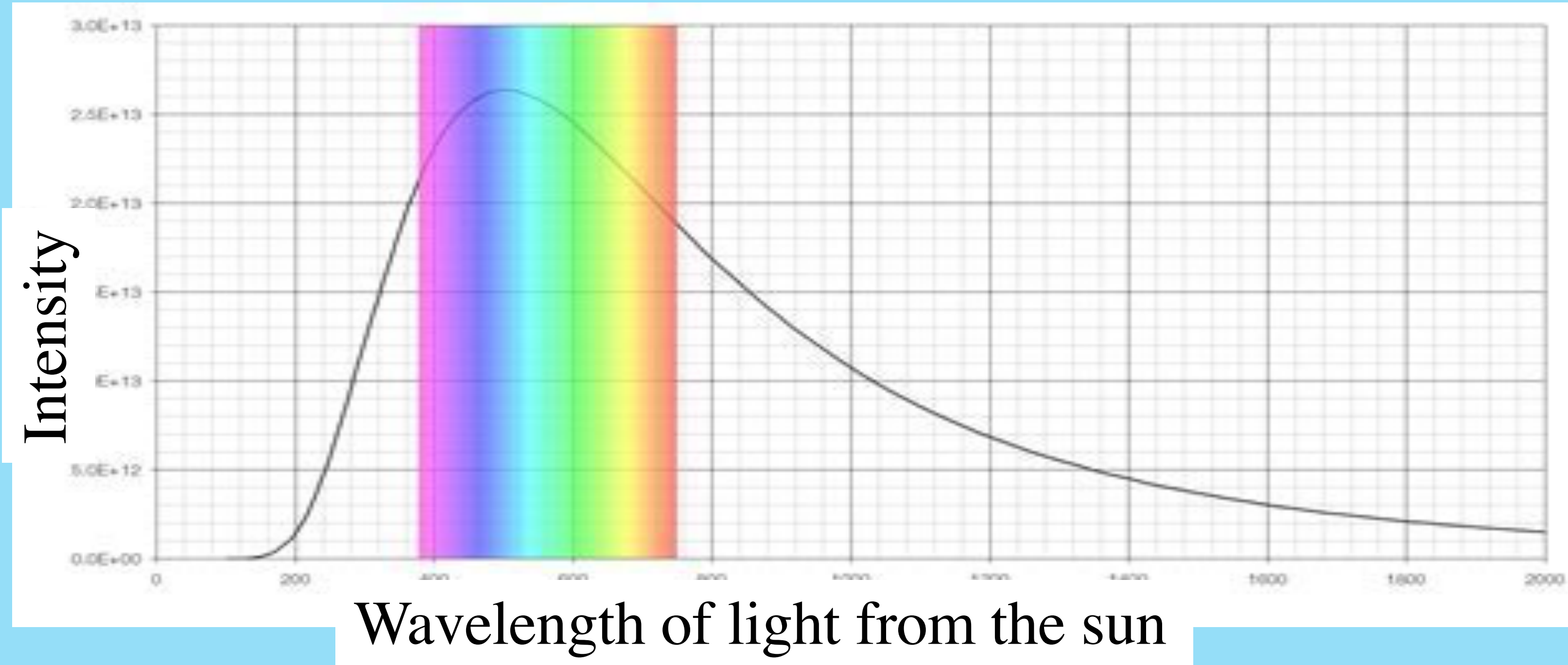


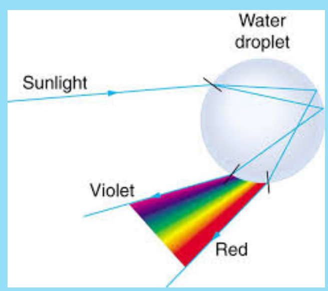


Visible 6000^{o}C

Infra-red 2-300^{o}C

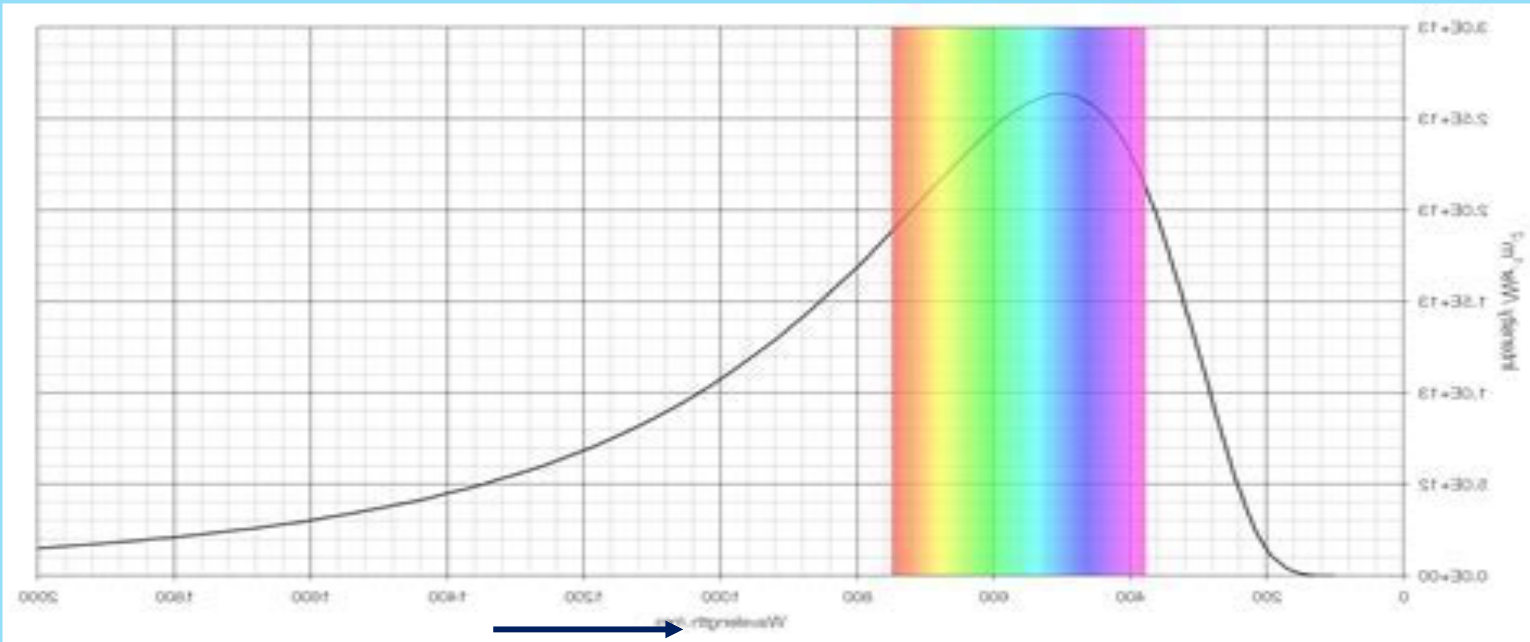
Consider the light from the sun





Which house has the gold?

What is the energy of a photon?

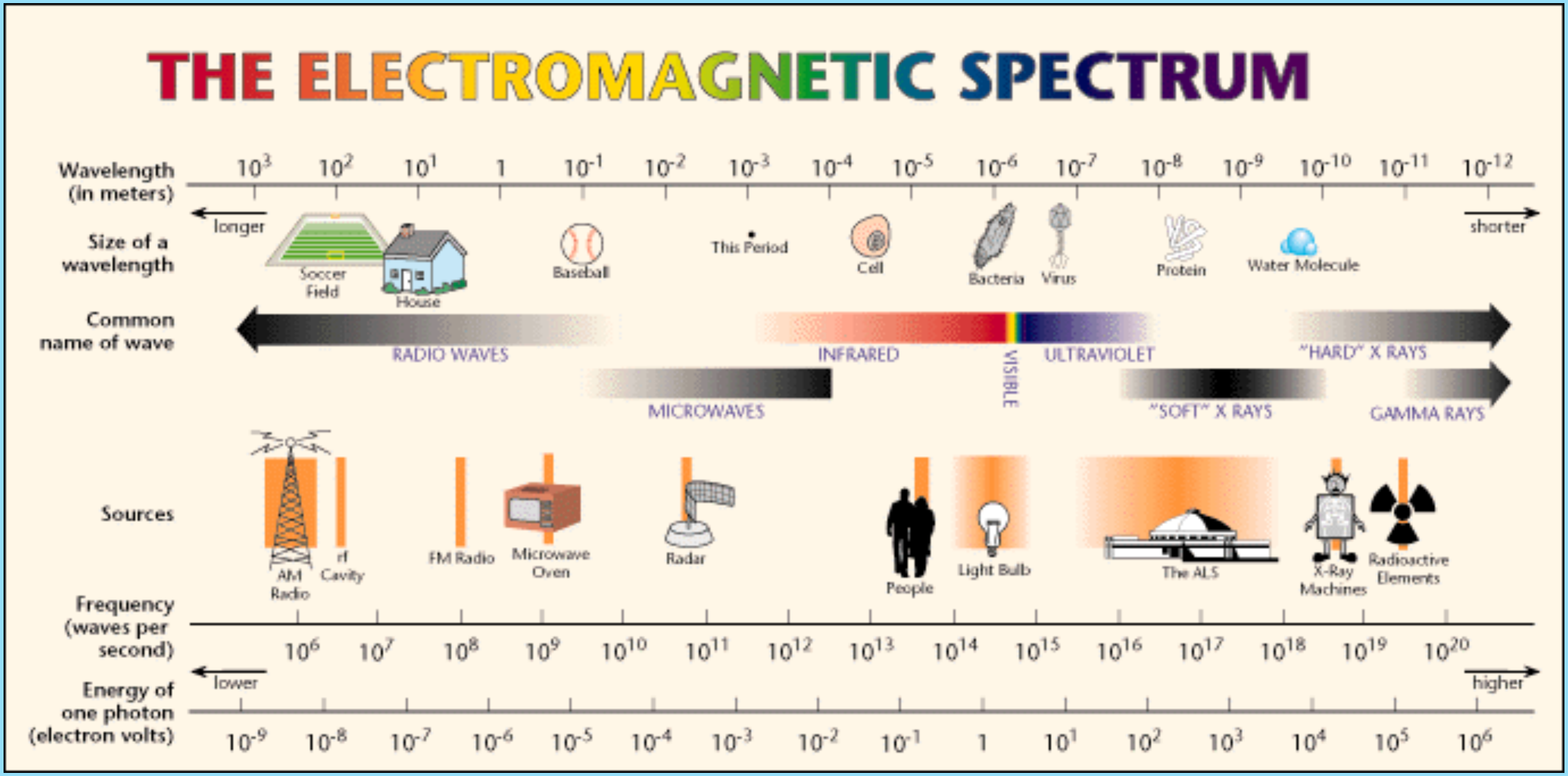


Frequency of light from the sun
Energy is proportional to the frequency

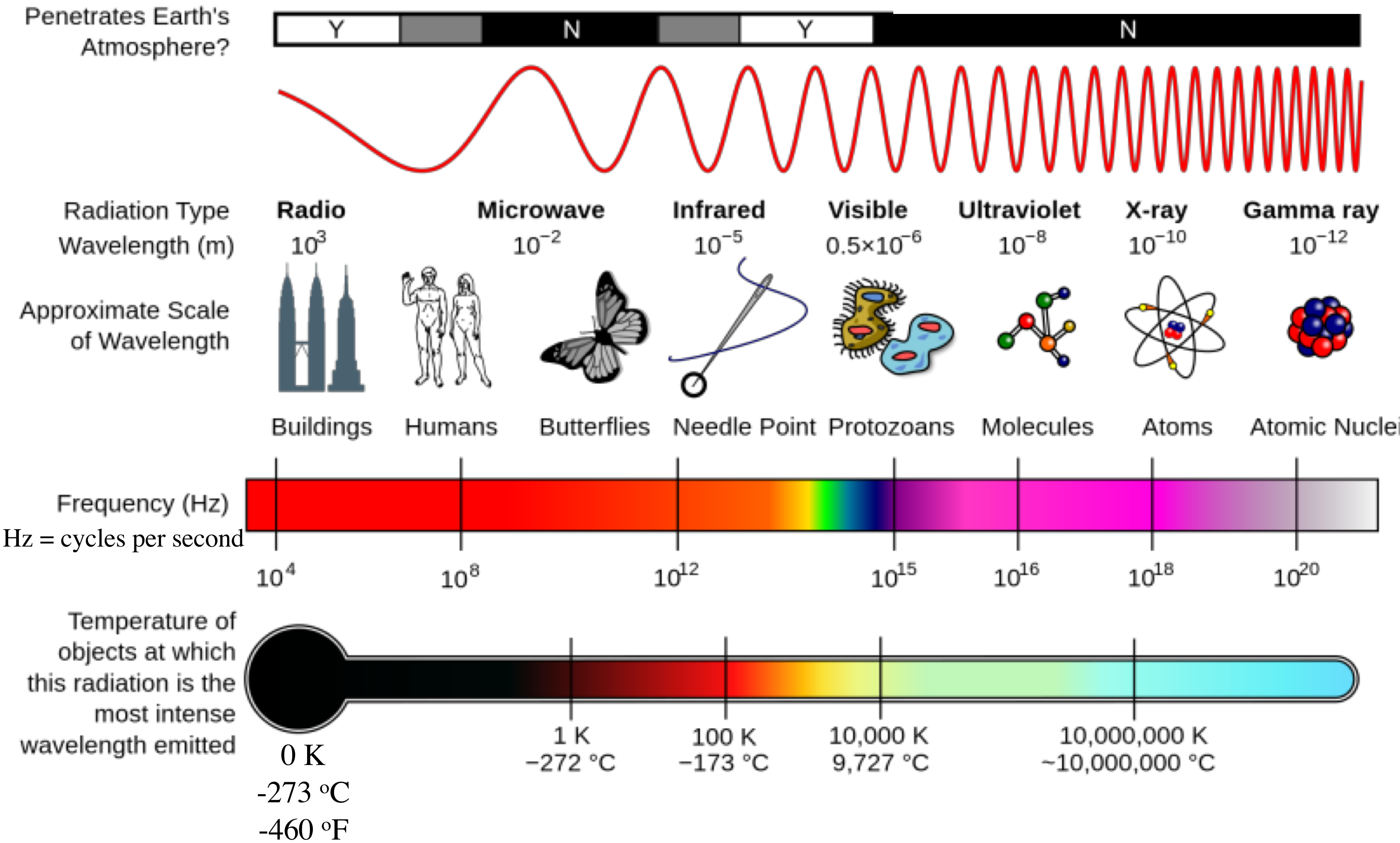
- The energy is quantized; hν; (h is Planck's constant)
  - Photons from the sun: 2.5 eV
  - Flux: 3.4×10^{21} photons/(s m^2)

Video on electromagnetic spectrum

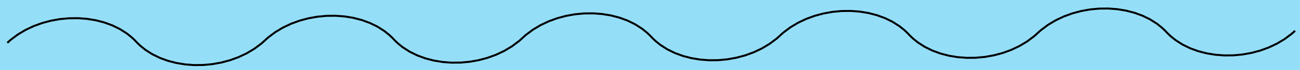
https://www.youtube.com/watch?v=cfXzwh3KadE



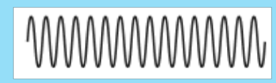
uv 3-100 eV x-rays 0.1-100 keV gamma-rays 1-10^6 MeV



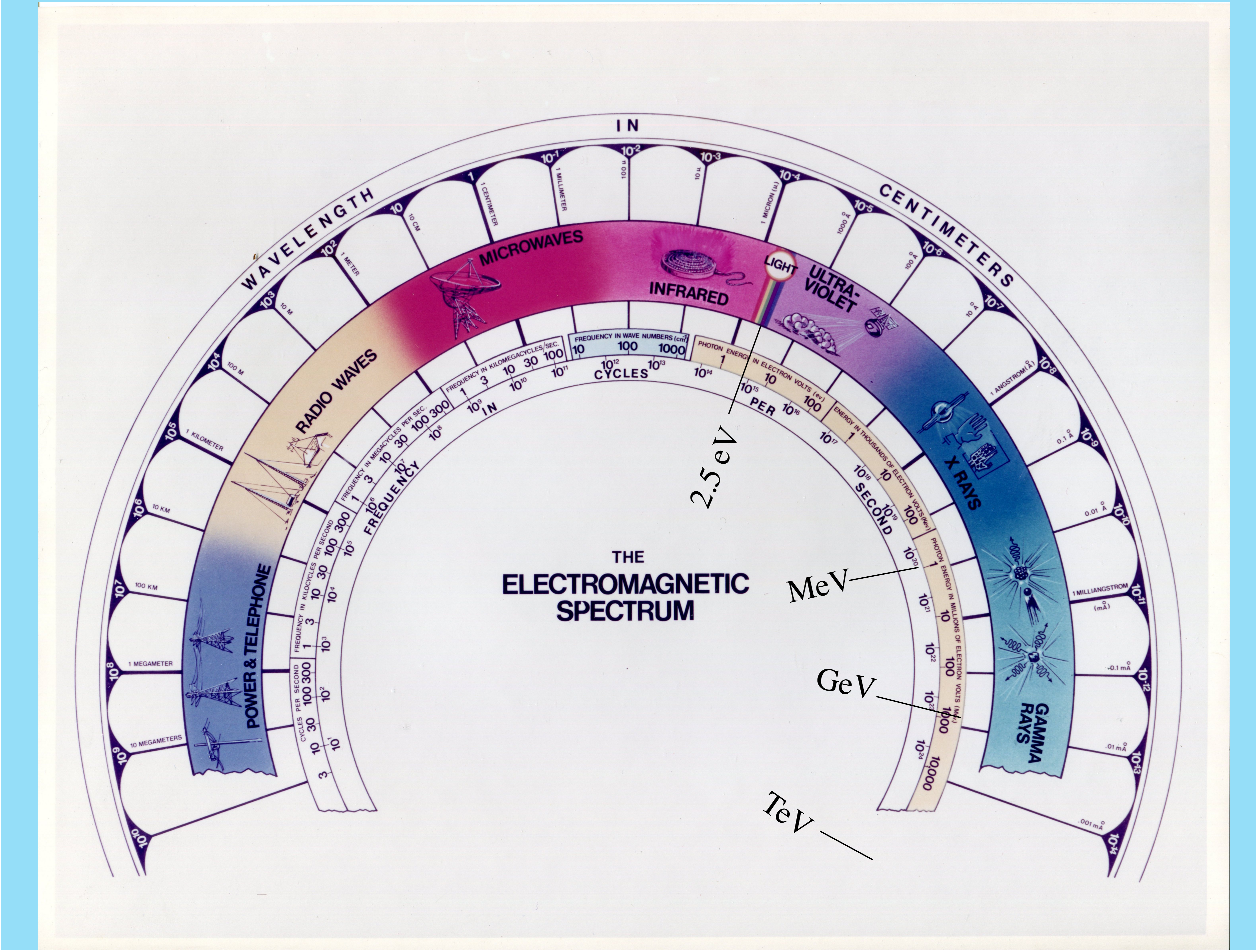
We represent a wave like this. You and your grandchild make waves like this on her jump rope.



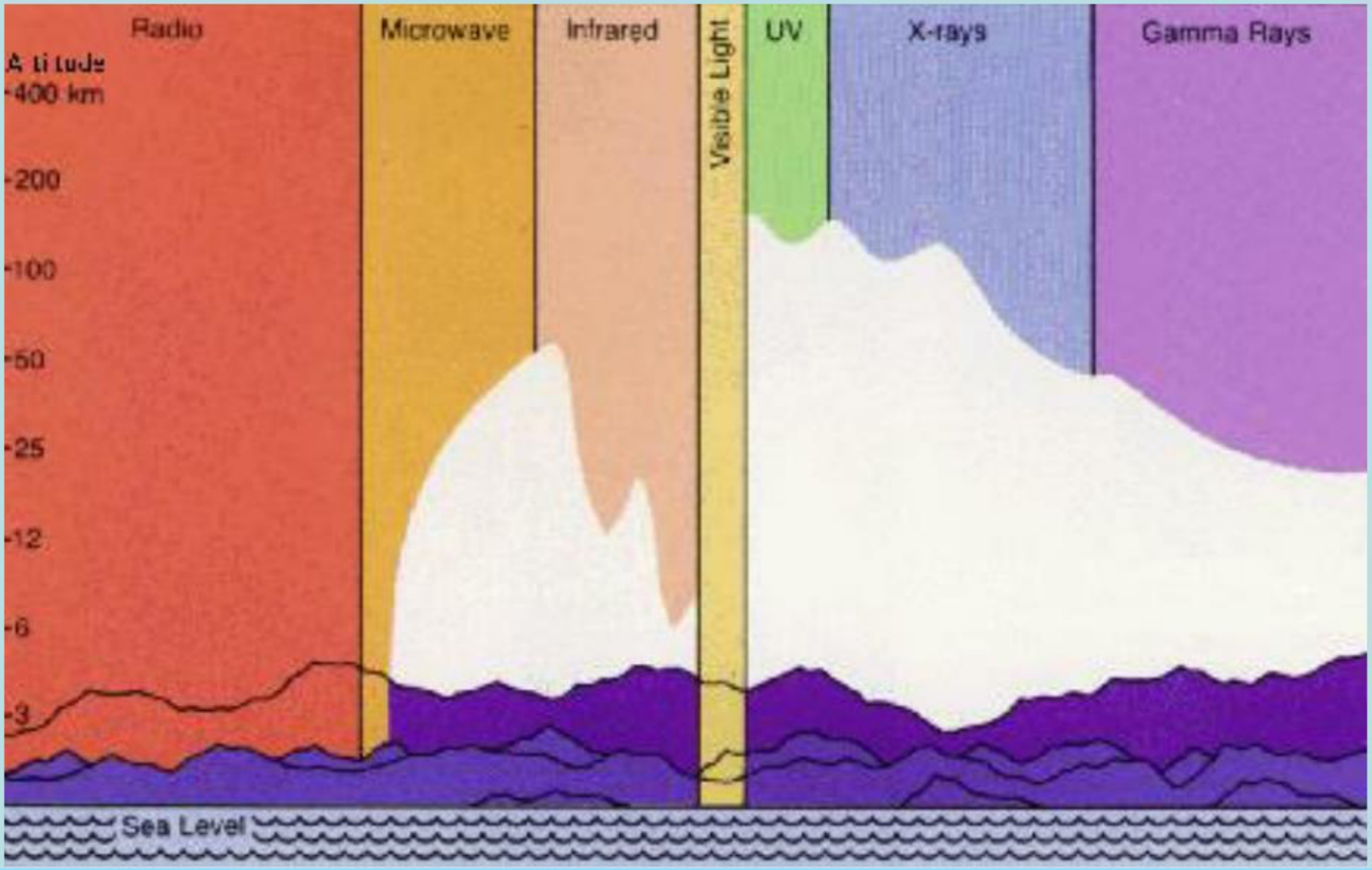
We represent a gamma ray like this.

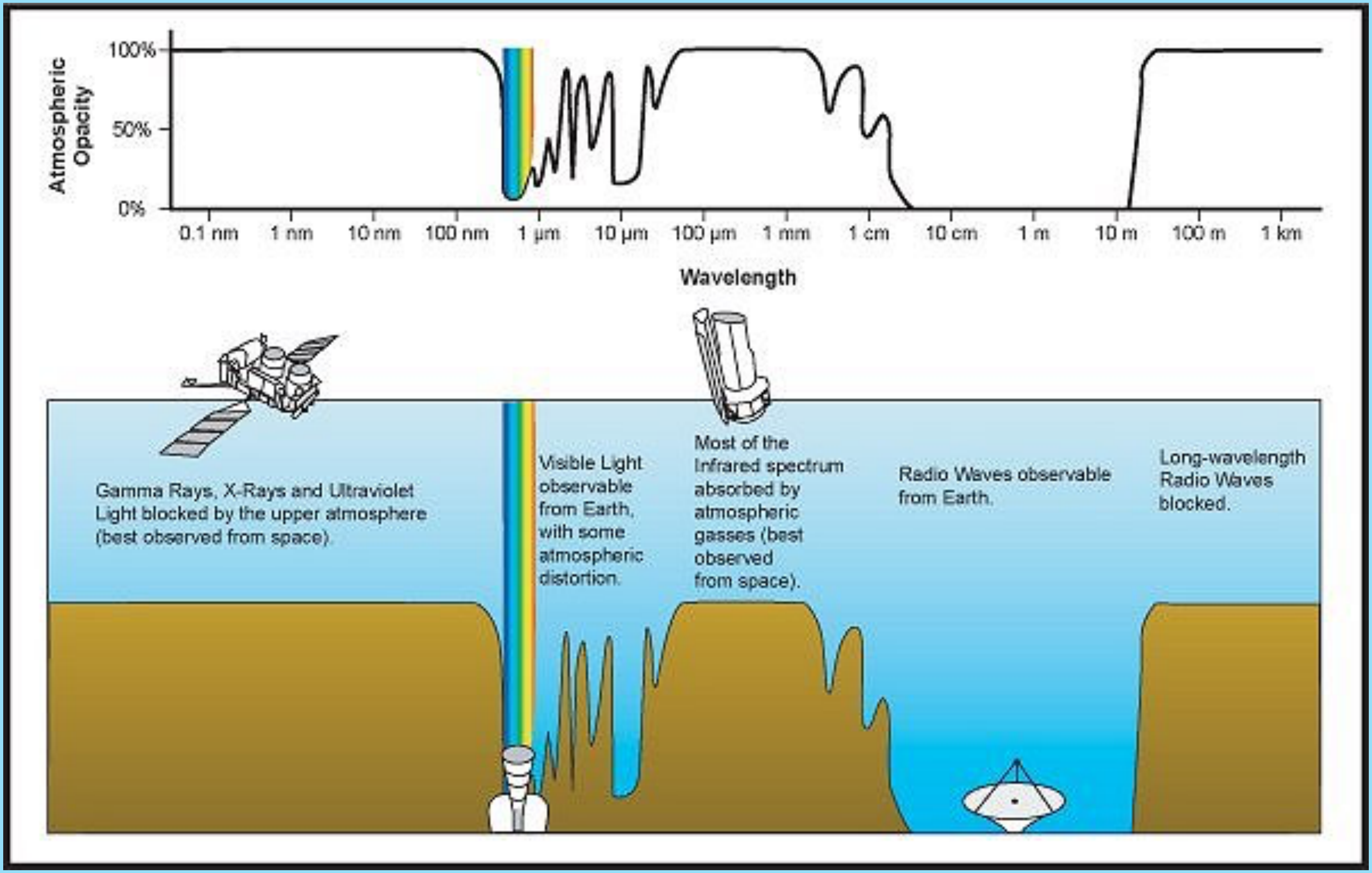


This comes nowhere near being enough cycles but just reminds the reader/viewer we are discussing gamma-rays rather than lower frequency radiation. Gamma rays range from 10^{19} Hz up to at least 10^{28} Hz. We will learn more about these gamma rays in a future class.


THE
ELECTROMAGNETIC
SPECTRUM
WAVELENGTH IN CENTIMETERS
POWER & TELEPHONE
RADIO WAVES
MICROWAVES
INFRARED
LIGHT
ULTRA-VIOLET
X RAYS
GAMMA RAYS
FREQUENCY IN CYCLES PER SECOND
2.5 eV
MeV
GeV
TeV

For some types of light, space is the only solution, as the atmosphere is opaque

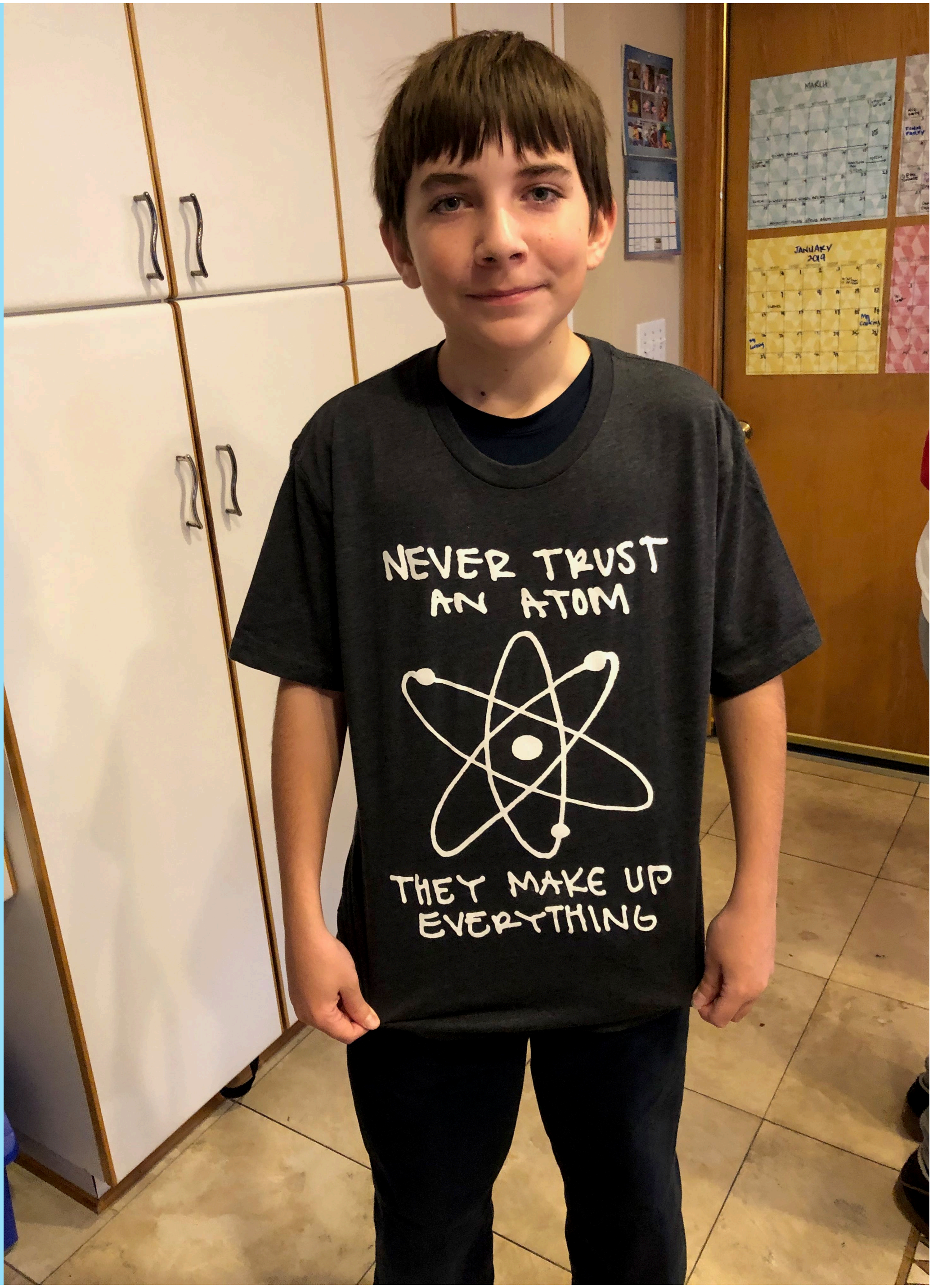




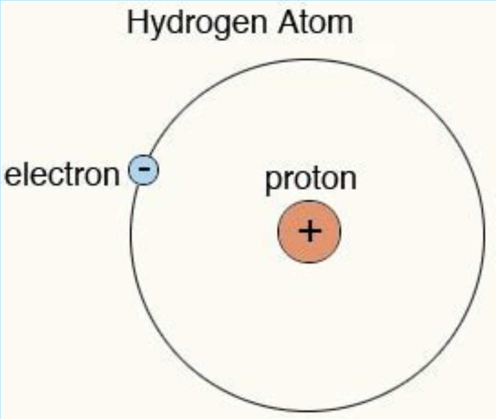
Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

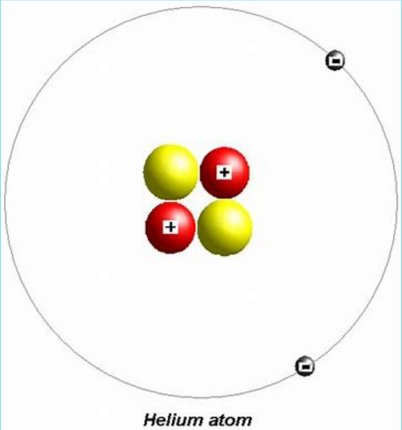
My 13 yr old grandson Ethan modeling his new T-shirt.

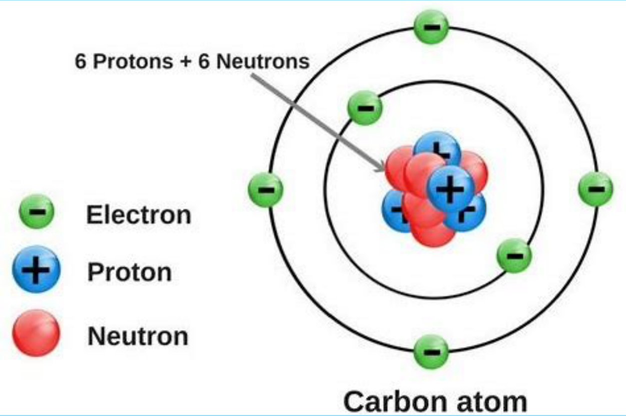
2/28/19



Size of atoms:
0.1 nanometer = 0.1 nm = 0.1 x 10^{-9} m







1.1 x 10^{-10} m

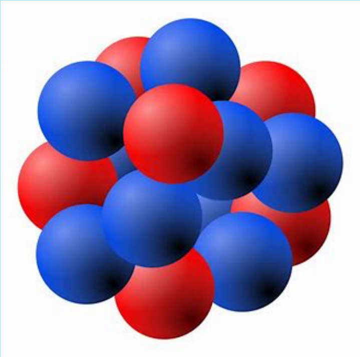
1.0 x 10^{-10} m

1.4 x 10^{-10} m

Size of nuclei ~10^{-15} m or femto meters

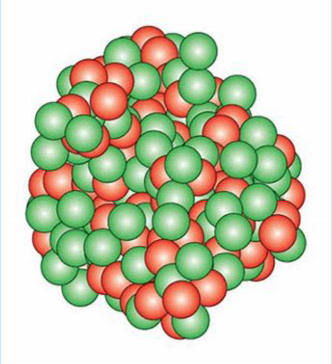
Size of nuclei: femtometer (10^{-15} m)

size of proton 0.84 x 10^{-15} m



Z=6, A = 12

Carbon nucleus, 6 neutrons
5.4 x 10^{-15} m



Z=92, A=238

Uranium nucleus
(146 neutrons)

15 x 10^{-15} m

size of electron 0.2 x 10^{-15} m
Four times smaller than a proton

What is a nanometer? -10^{-9} m

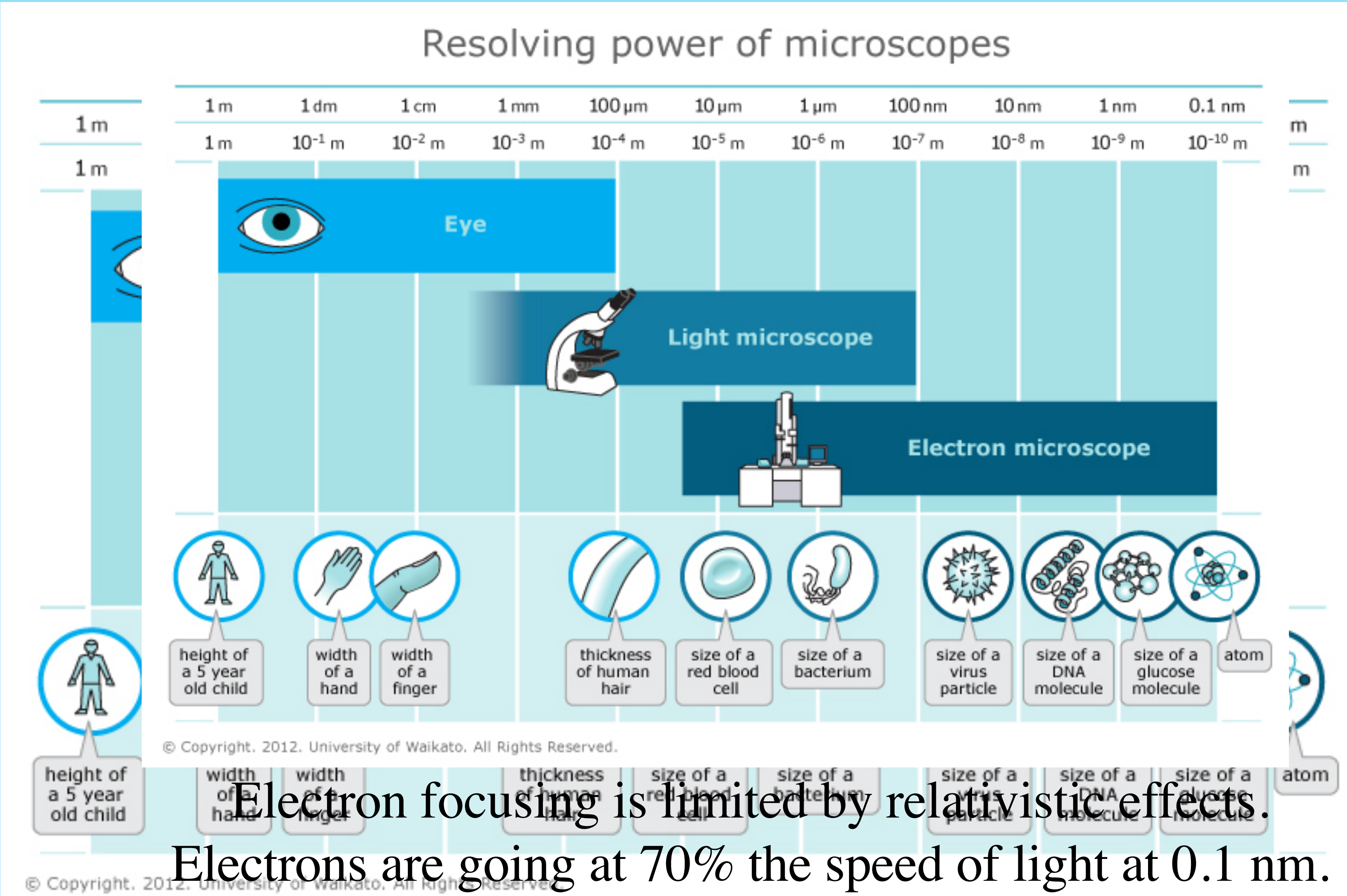
It is the size of a large molecule like glucose

It is 5 orders of magnitude (100,000 x) smaller than can be resolved by the human eye.

The de Broglie wavelength of an electron is 1.23×10^{-9} m. This applies to the ability to locate a free electron.

The electron in an atom is “in a box”, confined to a much smaller box. Since we know where it is, we can’t tell how fast it is going. Heisenberg’s Uncertainty principle.

How small a thing can an electron microscope see?



Electron focusing is limited by relativistic effects.

Electrons are going at 70% the speed of light at 0.1 nm.

What is a nanosecond? -10^{-9} s

Nano second= 10^{-9} seconds

A nanometer is the distance light can travel in
3×10^{-18} seconds.

The velocity of light: $c = 3 \times 10^{8}$ m/s = 1 ft/10^{-9} s= 1 ft/ns

c = 1 ft/ns

Earth to geosynchronous satellite – 0.11 s
Earth to moon – 1.3 s
Sun to Earth – 500 s = 8.3 min
Sun to 120 AU (Yoyager) – 16 hr
Sun to Alpha Centauri – 4.4 years

Neutrons

Neutrons are very much like protons, but they have no charge. They have essentially the same mass, and they both behave the same way in nuclei. (The same nuclear force.)

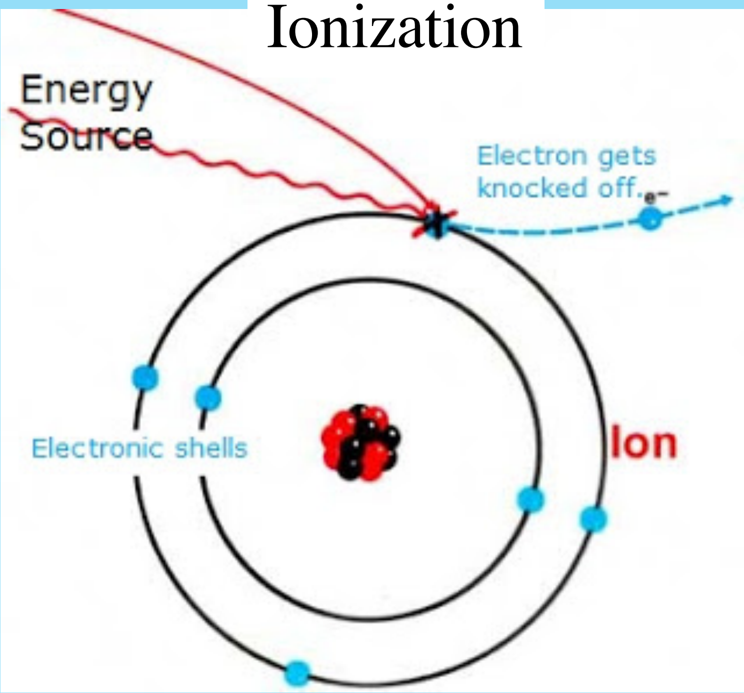
Groaners

A neutron walked into a bar and asked, "How much for a gin and tonic?" The bartender smiled wryly and replied, "For you, no charge."

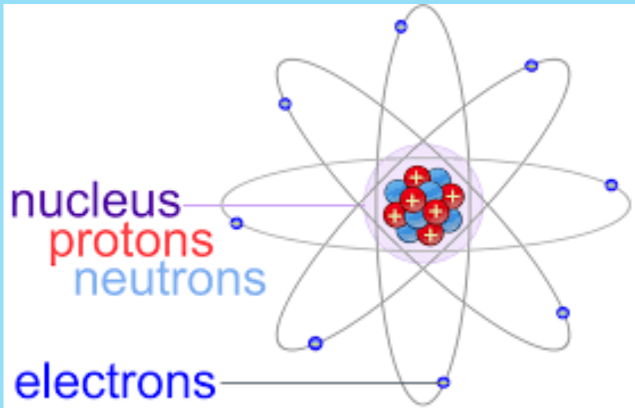
Two atoms were walking across a road when one of them said, "I think I lost an electron!" "Really!" the other replied, "Are you sure?" "Yes, I 'm absolutely positive."

Throw energy at an atom you kick off an electron and create an ion.

Ionization

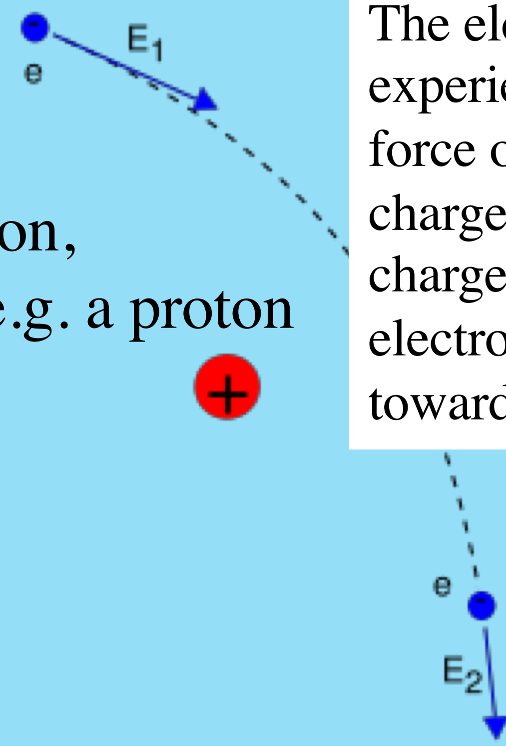


Protons and electrons: atoms and ions



You are familiar with this symbol of an atom, a nucleus surrounded by a cloud of electrons. Most of the mass is in the nucleus. The electrons are "bound" to the nucleus by the electric force.

For ions, the electrons have more energy and are not under the control of the nucleus. We call these ions and electrons (free).



ion,
e.g. a proton

The electron does experience the electric force of the ion. Like charges repel, unlike charges attract, so the electron is bent towards the ion.

Ions: atoms with one or more electrons removed.

For hydrogen it has mass A=1, charge Z=1 and we call it a proton, p.

For helium, if both electrons are removed, it has A=4, Z=2 and we call it an alpha particle. Alpha particles are emitted in radioactive decay of very heavy elements.

If a carbon has all 6 electrons removed, we still call it carbon (A=12, Z=6).

When ions get lots of energy in space we call them cosmic rays. We will see that they can be moving at essentially the speed of light.

What are the characteristics?

Electron

A = 1/1836; m_e = 0.511 MeV = 9.1×10^{-31} kg

Charge (Z) = -1

Size = 1.23×10^{-9} m de Broglie wavelength of free electron

Size = 1.23 nm

Size = 0.2×10^{-15} m Electron "in a box" localized by the electric force of the atom

Size = 0.2 fm

Proton (or a neutron)

A = 1; M_p = 938 MeV = 1.67×10^{-27} kg

Charge (Z) = +1

Size 0.84×10^{-15} m Diameter

Size = 0.84 fm

What is a nanometer? -10^{-9} m

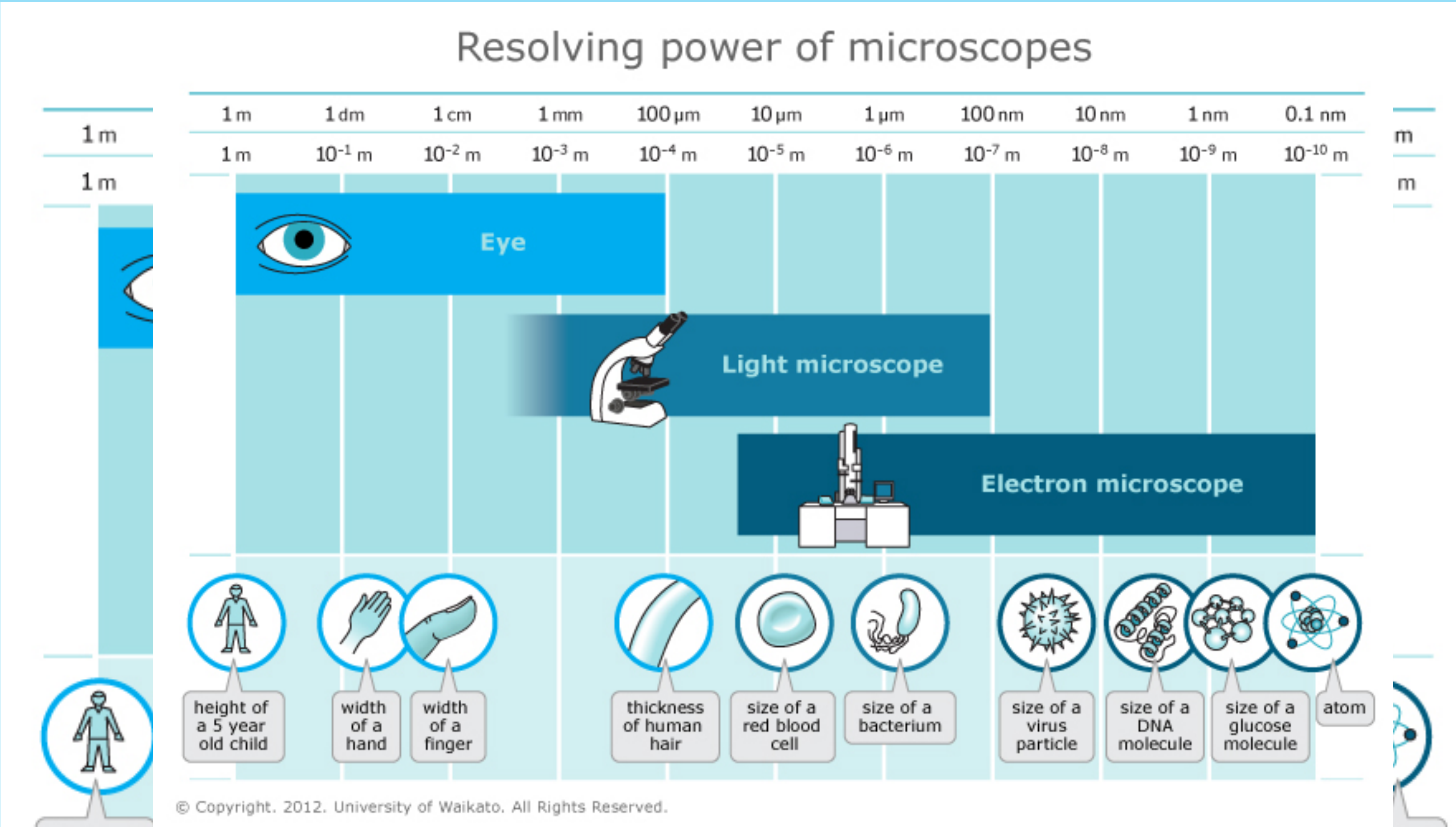
It is the size of a large molecule like glucose

It is the distance light can travel in a second

It is 5 orders of magnitude smaller than can be resolved by the human eye.

The de Broglie wavelength of an electron is $1.23\ 10^{-9}$ m

How small a thing can an electron microscope see?



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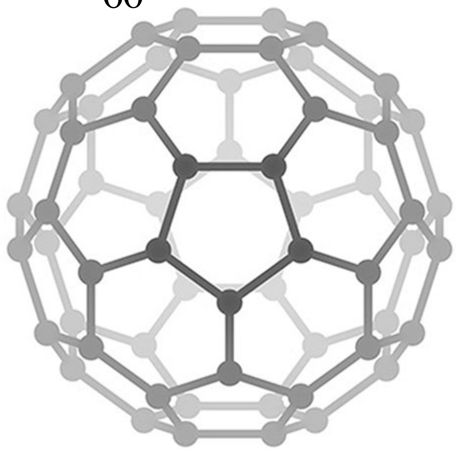
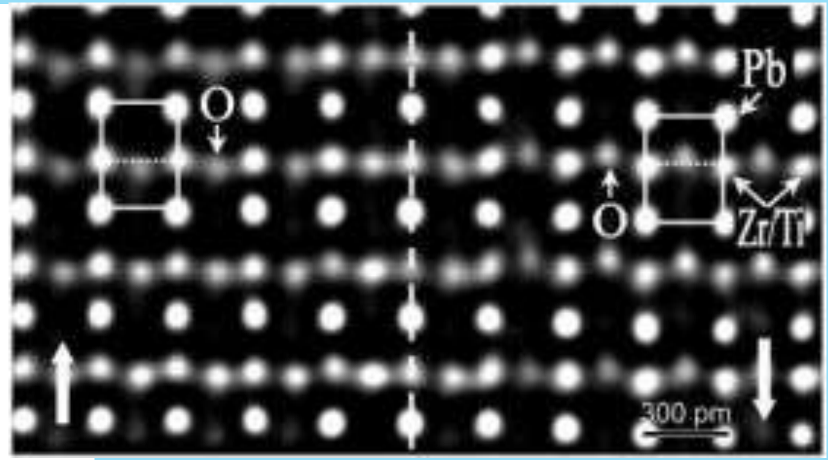
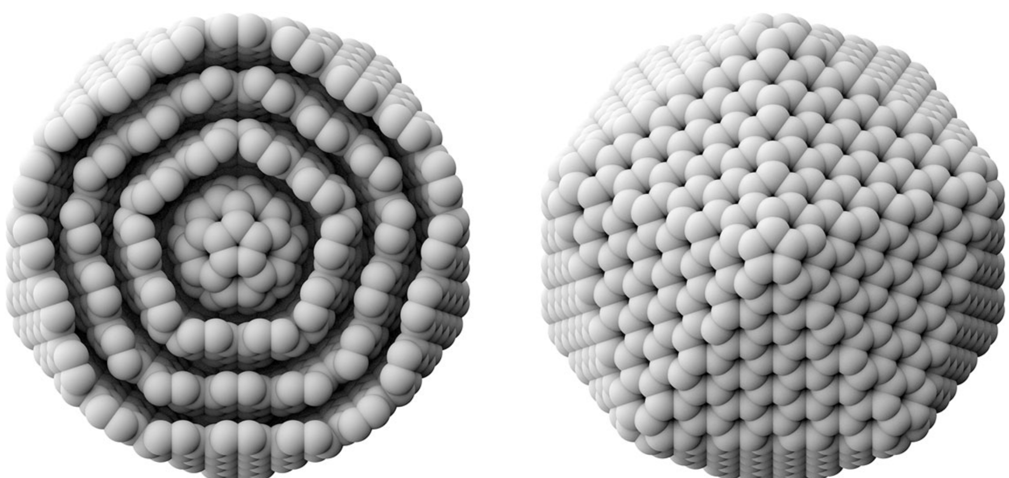
Carbon nanostructures

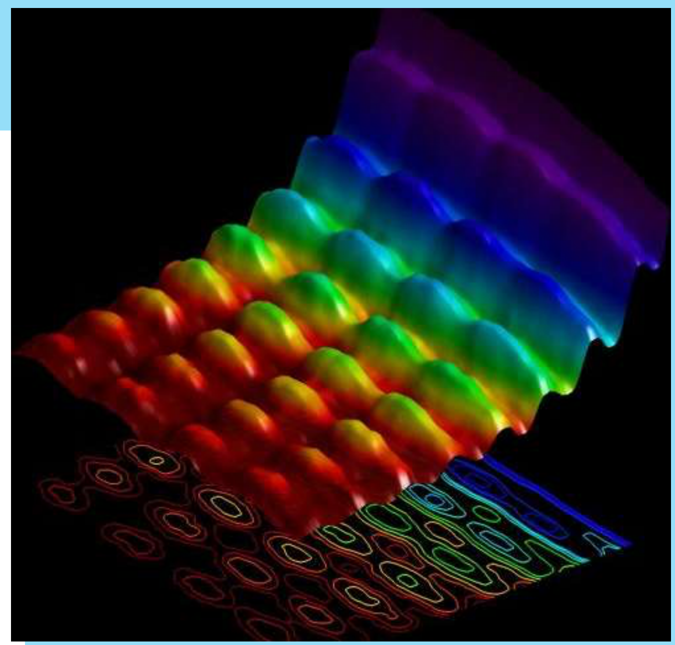
Fullerine C_{60}





carbon onion





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Charge (Z) = +1

Size 0.84×10^{-15} m

Size = 0.84 fm

Diameter

momentum

A measure of how hard it is to stop something from moving

Momentum is important in collisions

Momentum has a direction associated with it

Momentum is a vector

Vectors are symbolized by boldface type

Momentum is given by mass times velocity ($\mathbf{p} = m\mathbf{v}$)

Velocity v has a direction associated, so **v** is a vector.

Momentum is conserved

Recoil of a rifle

Billiard ball collisions

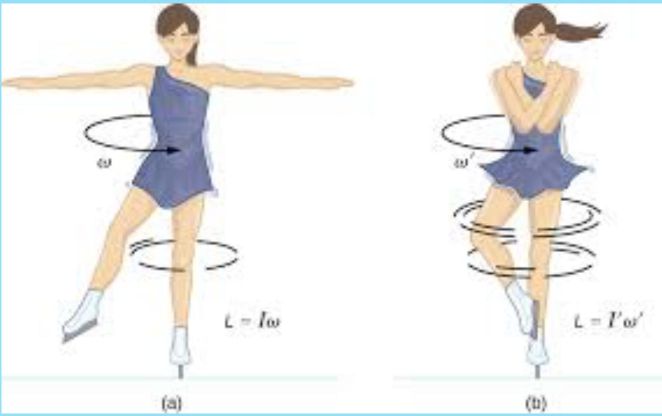
No change in momentum unless an outside force is applied.

Angular Momentum

A measure of how hard it is to stop something from moving

Angular momentum is the momentum associated with the rotation of an object. In this case the distribution of mass is important, because the linear speed is higher the further the matter is from the axis of rotation.

Skater with arms extended rotates faster as the arms are pulled in.



Angular momentum conserved
Change mass distribution,
Angular velocity changes.

Photons have momentum

A measure of how hard it is to stop something

Momentum is important in collisions

Momentum is given by mass times velocity

but photons have no mass

need to use relativistic equations

Photons can collide and transfer momentum

$p = h/\lambda$; since $\lambda\nu = c$, $p = h\nu/c$

The direction is the direction of the photon

The energy of a photon is given by $h\nu$.

So the momentum and energy of a photon are closely related.

We will explore this in more depth later.