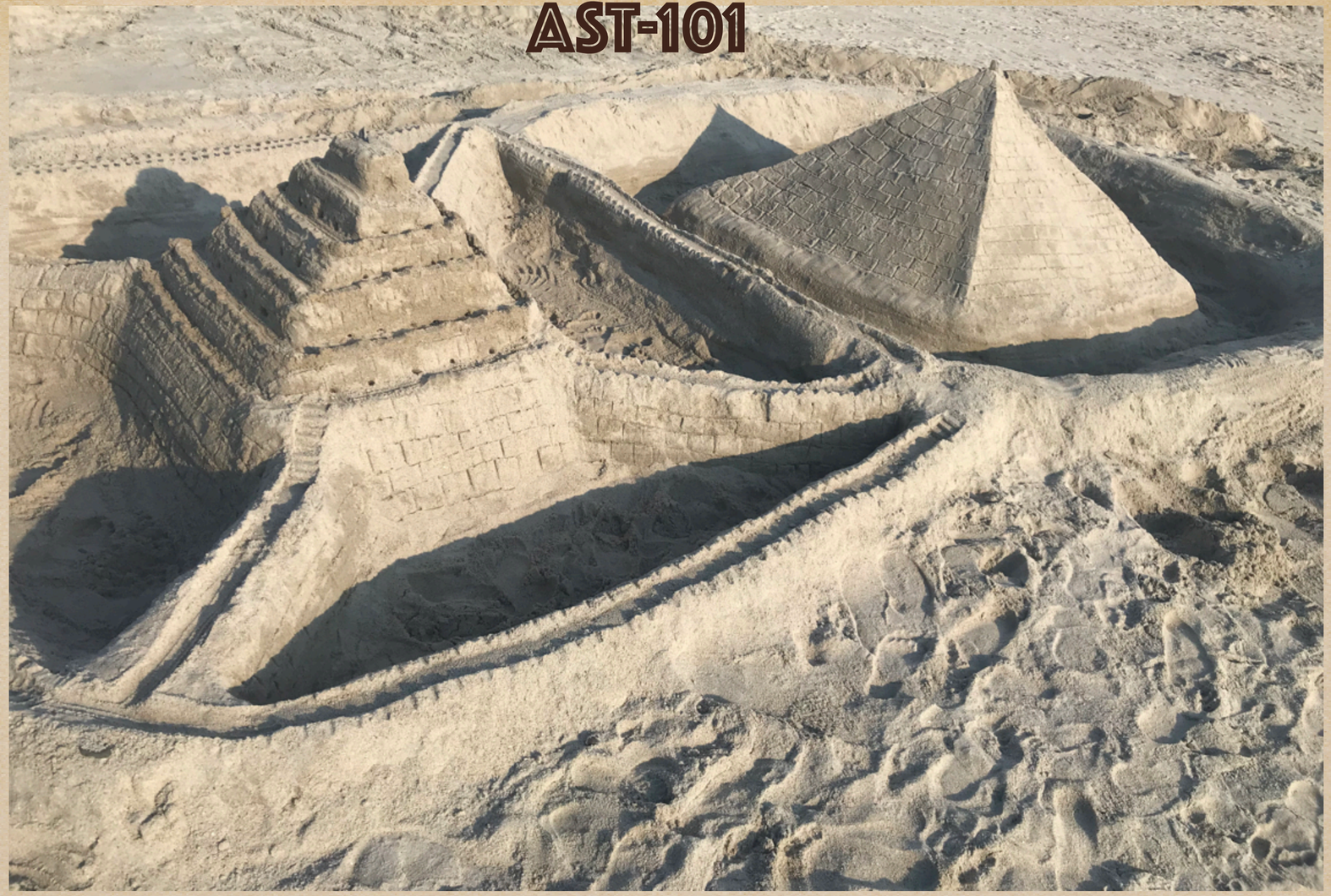
AST-101



What are stars made of?

Luis Anchordoqui

Did you ever wonder what stars are made of?

You might not be surprised to know that stars are made of the same stuff as the rest of the Universe:

73% hydrogen, 25% helium, and the last 2% is all other elements

That's it

Except for a few differences here and there

stars are made of pretty much the same stuff

But... how did we learn that?

LIGHT

For nearly all astronomical objects, light brings us our only information

Need to understand what light is and how it interacts with matter

Light is a form of ENERGY

White light is made up of many different colors

Wave-Particle Duality of Light

. Light can behave like a wave

- Frequency, wavelength, amplitude

. Light can also behave like a particle

- Photons, discrete amounts of energy = quanta

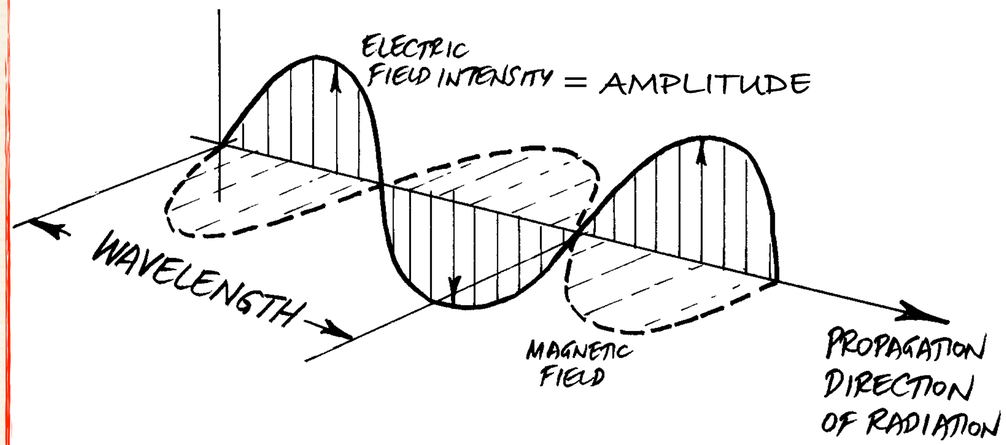
Light as a WAVE

Anatomy of a Wave

- Speed of light is the SAME for all wavelengths
- The shorter the wavelength, the more cycles pass per second
- How to remember equation?

– Unit Analysis!

ELECTROMAGNETIC RADIATION AS A WAVE



$$\lambda \times f = c$$

WAVELENGTH × FREQUENCY = SPEED OF "LIGHT"

$$\lambda = c/f \quad , \quad f = c/\lambda$$

PROPAGATION SPEED OF ALL EM WAVES IS THE SAME!

C IS A CONSTANT $\approx 300,000$ Km/sec

$= 3 \times 10^{10}$ cm/sec

Light as a PARTICLE

- Light can also be thought of as a particle ☛ photon

~~Not proton~~

- A photon is a mass-less particle of electromagnetic radiation energy

- Wave-particle duality seen in other particles (e.g., electrons) as well

Photon Energy Depends on Frequency/Wavelength

QUANTUM MECHANICS

Photon Energy = Planck's constant x frequency

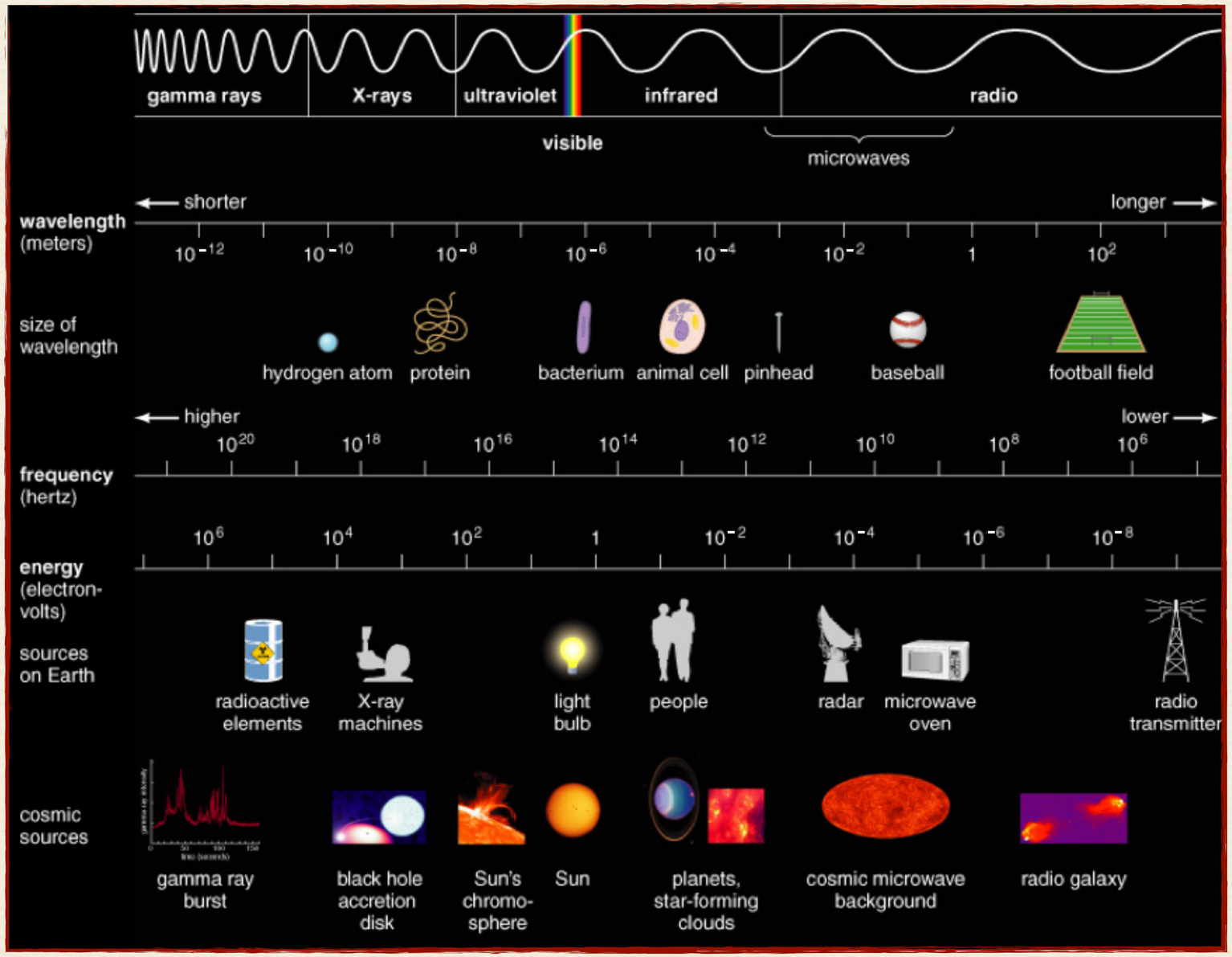
$$E = h \times f$$

Higher frequencies or shorter wavelengths $\Rightarrow$ **MORE ENERGY**

(UV, X-rays more DANGEROUS!)

$E \propto f$ $\quad$ $E \propto 1/\lambda$

The Electromagnetic Spectrum



What is LIGHT?

A. Light is a wave, like sound only much faster

B. Light is like little particles ← each one is a photon

C. Light is the absence of dark.

D. A kind of energy we model with some of the properties of waves and some properties of particles

What is LIGHT?

A. Light is a wave, like sound only much faster

B. Light is like little particles ☛ each one is a photon

C. Light is the absence of dark.

D. A kind of energy we model with some of the properties of waves and some properties of particles

When compared to RED light ($\lambda = 700$ nm), Blue light ($\lambda = 400$ nm) is:

A. Longer wavelength

B. Lower Frequency

C. Higher energy photons

D. Faster photons

When compared to RED light ($\lambda = 700$ nm), Blue light ($\lambda = 400$ nm) is:

A. Longer wavelength

B. Lower Frequency

C. Higher energy photons

D. Faster photons

SO FAR

LIGHT

NEXT

MATTER AND THE INTERACTION OF LIGHT WITH MATTER

Four Ways in Which Light can Interact with Matter

1.- Emission - matter releases energy as light

2.- Absorption - matter takes energy from light

3.- Transmission - matter allows light to pass through it

4.- Reflection - matter repels light in another direction

Four Ways in Which Light can Interact with Matter

1.- Emission - matter releases energy as light

2.- Absorption - matter takes energy from light

3.- Transmission - matter allows light to pass through it

4.- Reflection - matter repels light in another direction

Four Ways in Which Light can Interact with Matter

1.- Emission - matter releases energy as light

2.- Absorption - matter takes energy from light

3.- Transmission - matter allows light to pass through it

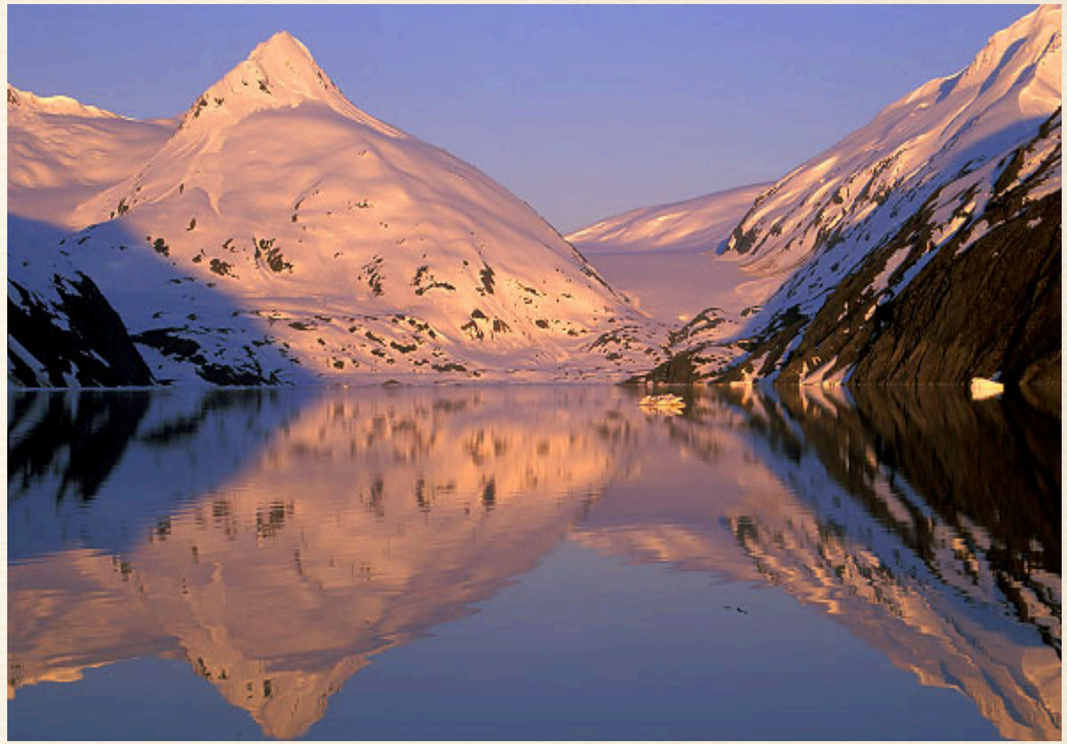
4.- Reflection - matter repels light in another direction

Four Ways in Which Light can Interact with Matter

1.- Emission - matter releases energy as light

2.- Absorption - matter takes energy from light

3.- Transmission - matter allows light to pass through it



4.- Reflection - matter repels light in another direction

Why is a rose red?

A. The rose emits red light

B. The rose absorbs red light

C. The rose transmits red light

D. The rose reflects red light

Why is a rose red?

A. The rose emits red light

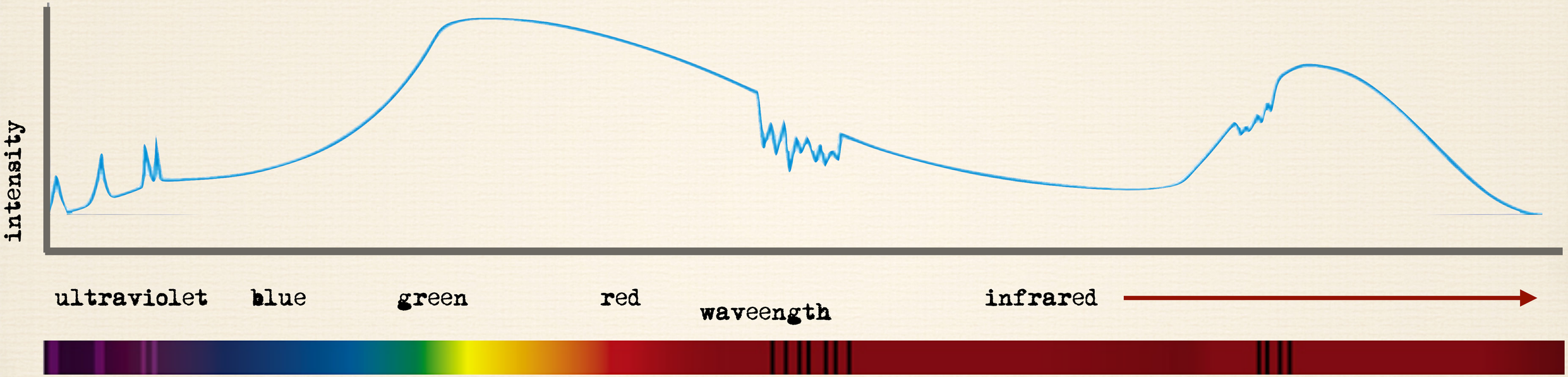
B. The rose absorbs red light

C. The rose transmits red light

D. The rose reflects red light

Light as Information Bearer through its interaction with matter

We can separate light into its different wavelengths (spectrum)



By studying the spectrum of an object, we can learn its composition, temperature and velocity

To understand the interaction of light with matter need a microscopic description of matter

Matter: a Material World

ATOM ☛ nucleus made of protons and neutrons

A cloud made of electrons surrounds the nucleus

Electrons are held onto the atom by electric force

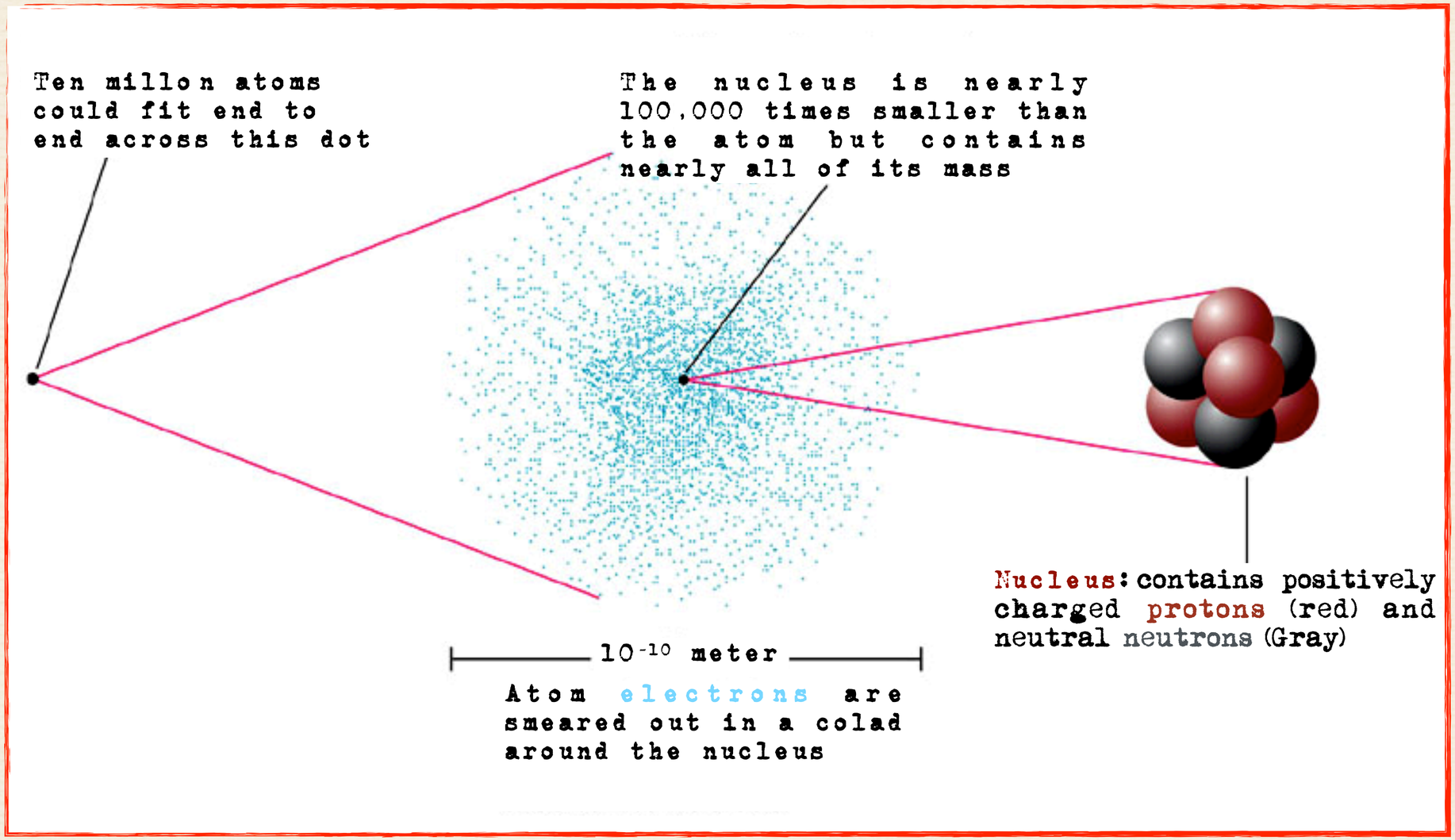
Electrons have negative electric charge

Protons have positive electric charge

Neutrons are neutral

Electrically neutral atoms have the same number of protons and electrons

Atoms Involve Big Empty Spaces



Hydrogen: simplest and most common

Hydrogen (^{1}H)

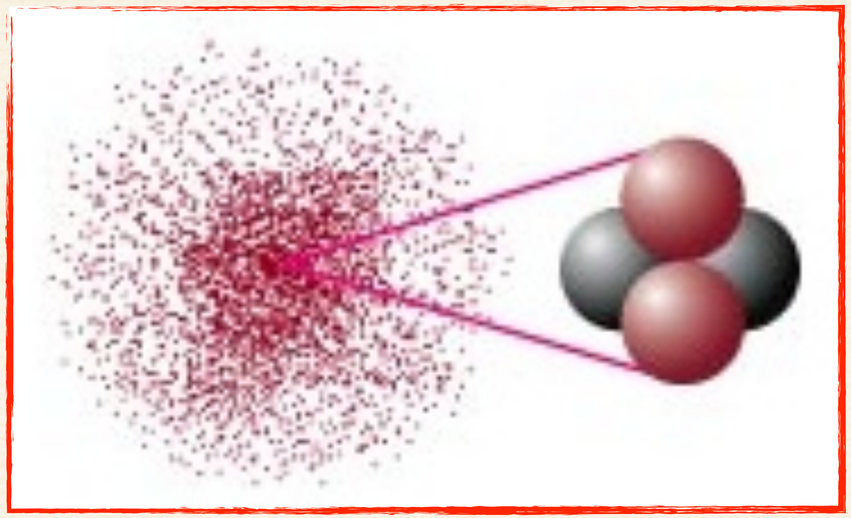
atomic number 1

atomic mass number 1

(1 electron)

Helium

Helium (^4He)



atomic number 2

atomic mass number 4

(2 electrons)

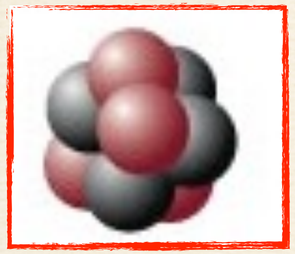
- The number of protons (atomic number) characterizes a certain chemical element
- Mostly an atom will have a certain normal number of neutrons along with the protons
- But occasionally, an atom will have a few more or less neutrons than normal

  This is called an isotope of that element

Carbon Isotopes

Different isotopos of a given element contain the same number of protons, but different numbers of neutrons

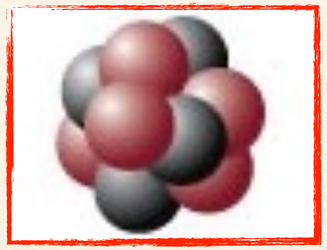
carbon-12



^{12}C

6 protons
+
6 neutrons

carbon-13



^{13}C

6 protons
+
7 neutrons

carbon-14

^{14}C

6 protons
+
8 neutrons

Deuterium is an isotope of Hydrogen Which of the following makes sense for the composition of Deuterium?

A. 1 proton, 0 neutrons, 1 electron

B. 2 protons, 0 neutrons, 2 electrons

C. 2 protons, 2 neutrons, 2 electrons

D. 1 proton, 1 neutron, 1 electron

Deuterium is an isotope of Hydrogen Which of the following makes sense for the composition of Deuterium?

A. 1 proton, 0 neutrons, 1 electron

B. 2 protons, 0 neutrons, 2 electrons

C. 2 protons, 2 neutrons, 2 electrons

D. 1 proton, 1 neutron, 1 electron

Periodic Table of the Elements

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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
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
55 Cs	56 Ba	57–71 La–Lu	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
87 Fr	88 Ra	89–103 Ac–Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									

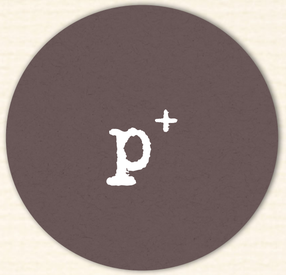
Lanthanoids	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinoids	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Atomic Number = # of protons in nucleus

Atomic Mass Number = # of protons + neutrons

What if an electron is missing?

Ion



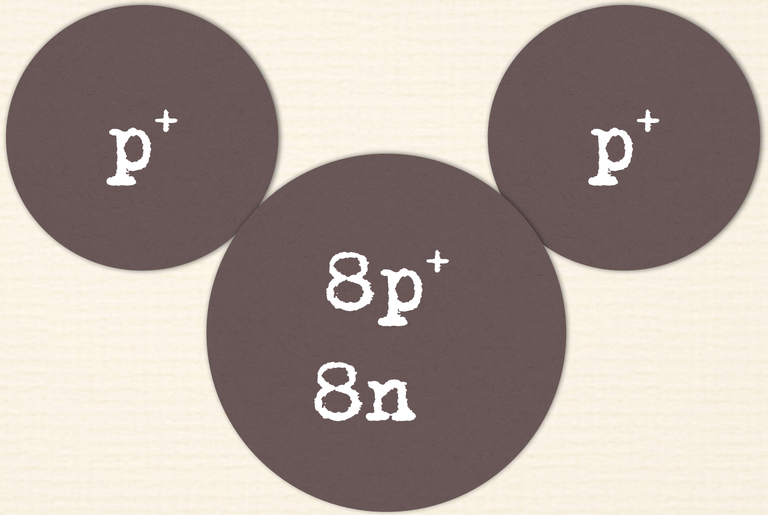
Atomic Number = 1

Atomic Mass Number = 1

H^{+1}

What if two or more atoms combine to form a particle?

molecule



H_2O ☛ water

Light and Atoms

- Light interacts with atoms in specific ways

- Allows us to measure properties of the object such as composition & temperature

- The key ☛ the spectrum of an object
  (intensity as a function of wavelength)

Energy Levels in Atoms

Electrons in atoms do NOT orbit around the nucleus like little planets - their position better described by probability waves

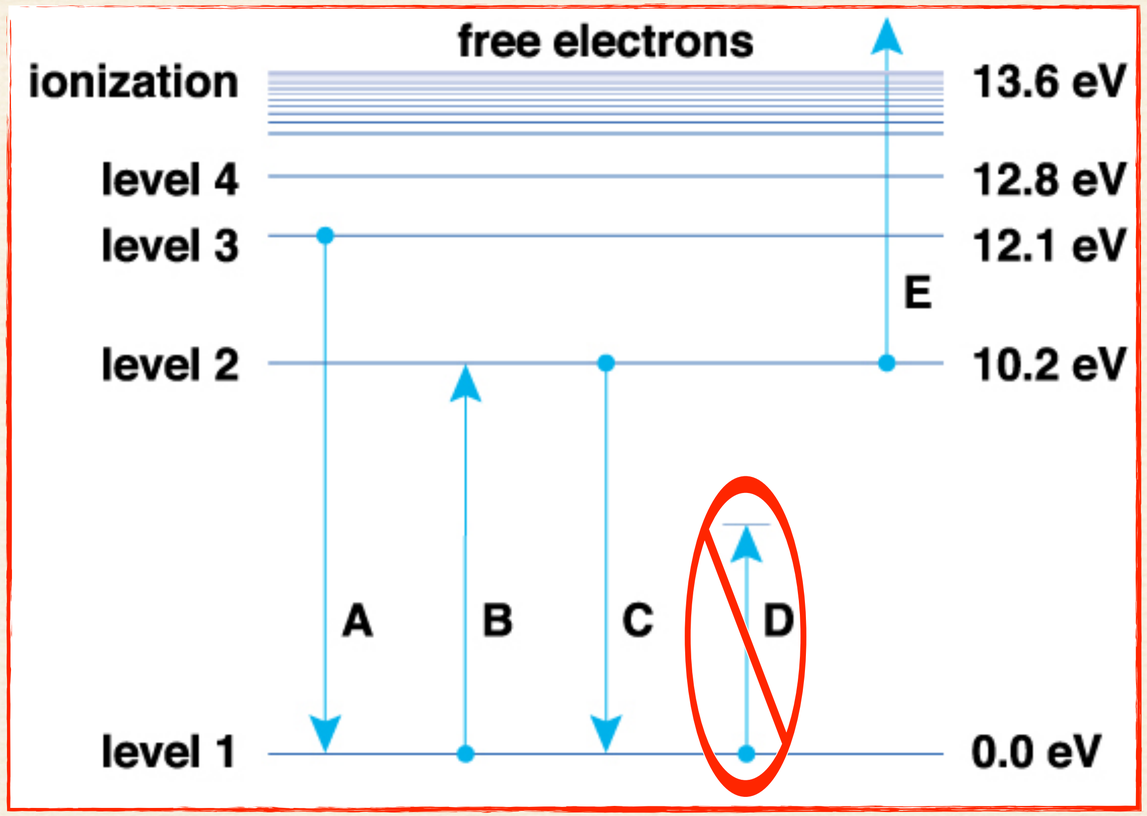
However, they do move in different energy states some electrons in a given atom have more energy than others

These energy states are quantized- there are only certain energies that the electrons are allowed to have

This is quantum physics

How do electrons move between levels?

Electrons can move between levels if they are given or give out the exact amount of energy corresponding to the difference in the energy levels



Example ☛ Energy jumps A, B and C allowed; D is not possible for this atom, E ionizes the atom with an energy gain of >3.4 eV

- Each atom has a different set of energy levels ! different spectrum
- Identification of spectral lines allows to determine the composition of a celestial object

helium

sodium

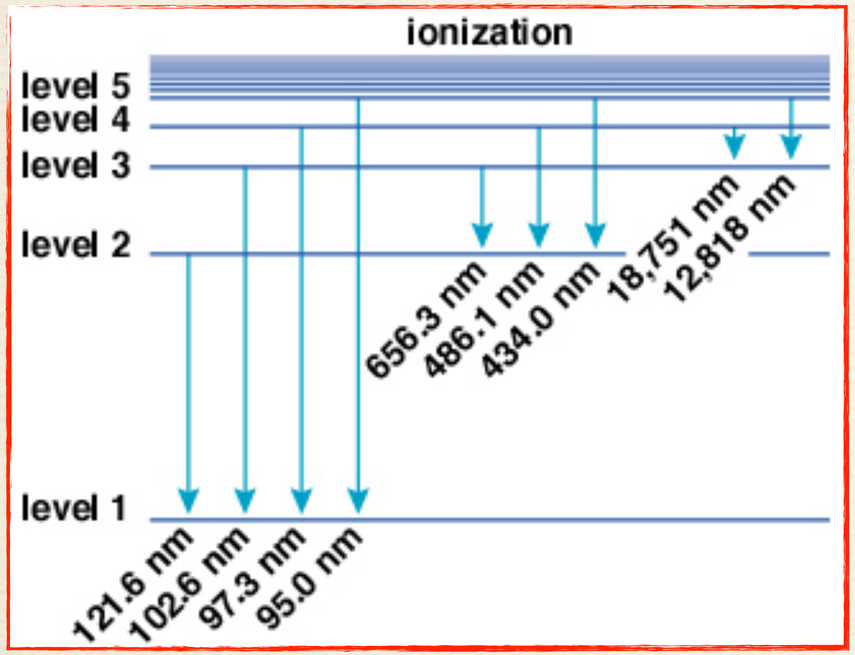
neon

Where does that energy come from (energy increase) or go to (energy decrease)??

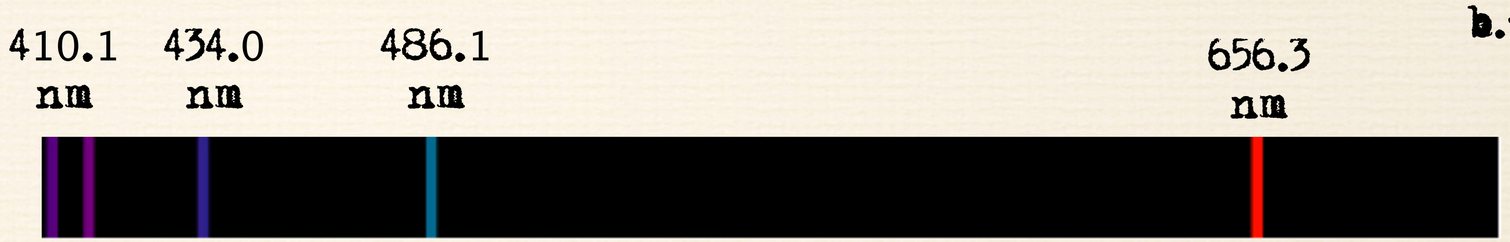
PHOTONS!

The energy change between levels is equal to the energy of the photon

a.-



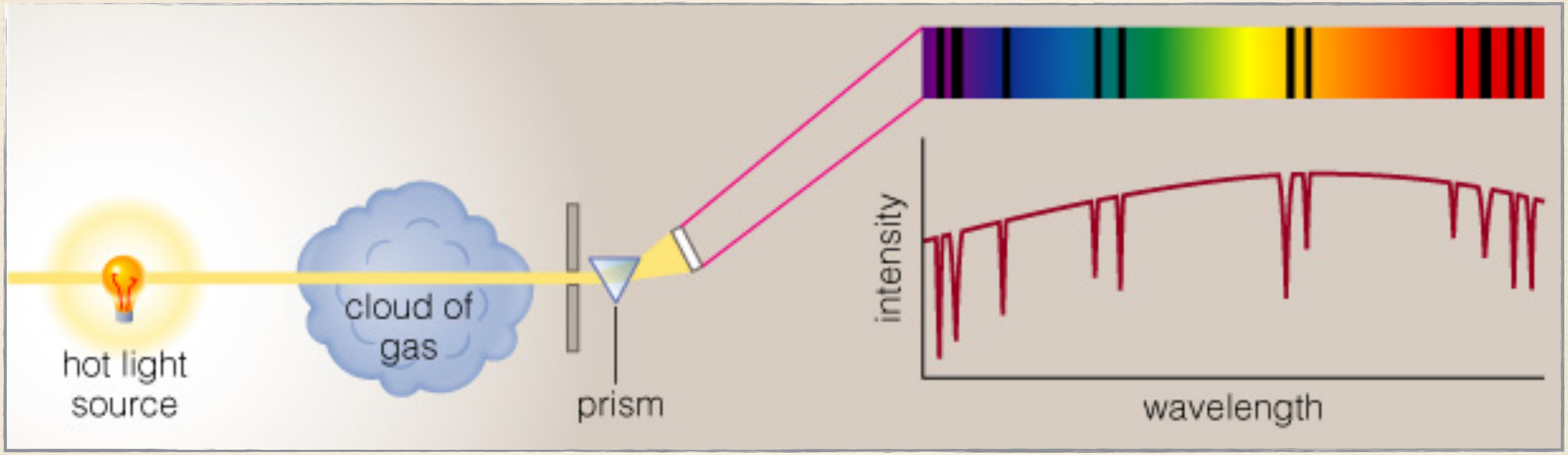
b.-



c.-

Larger energy jumps will be SHORTER wavelength photons!

Absorption Spectrum



Absorption Line Spectrum

If light with a continuous spectrum shines through a cloud of COOL gas with electrons in low-energy states, the gas can absorb photons OF THE RIGHT ENERGIES to move electrons to excited states

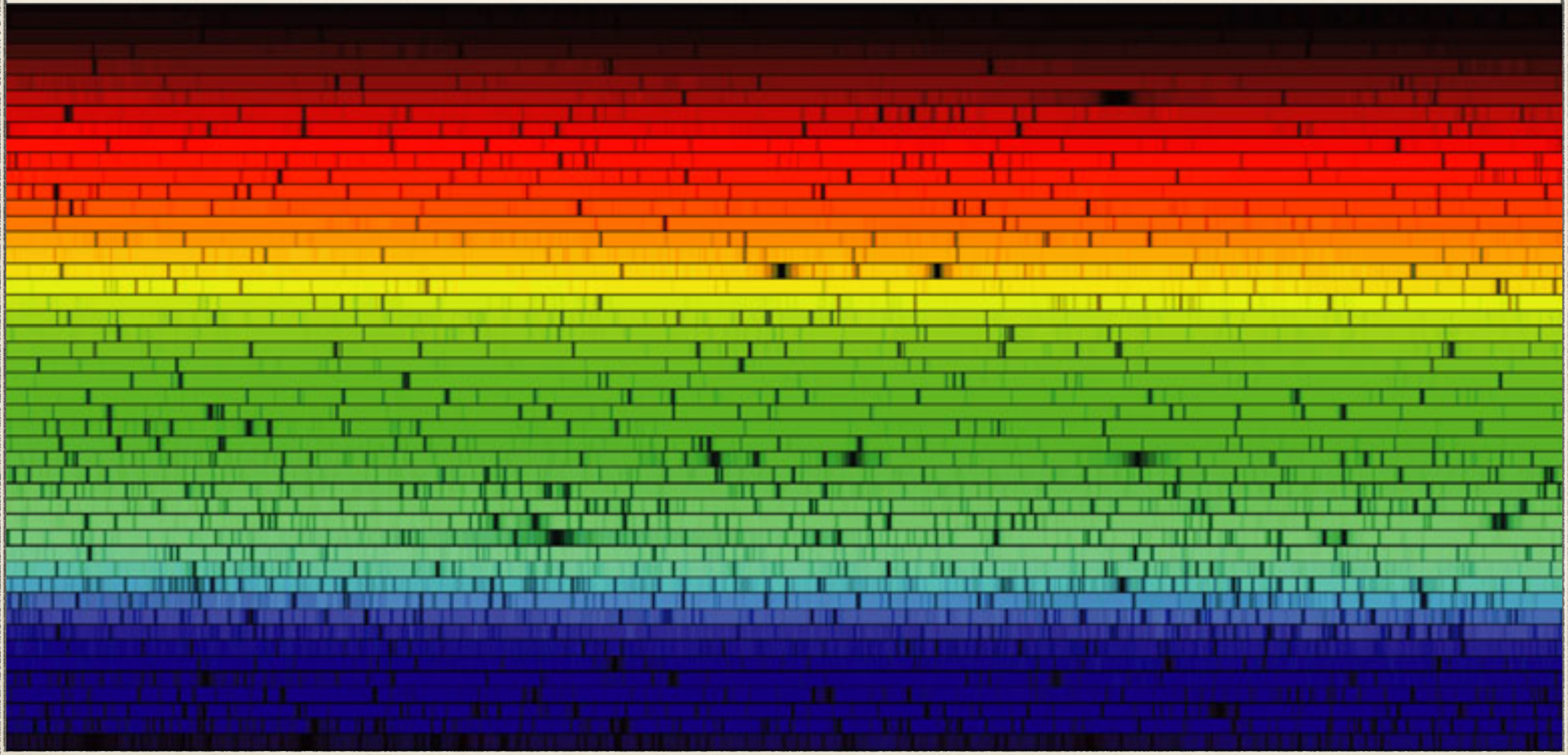
- Resulting spectrum shows DARK LINES of absorption

* Corresponds to wavelengths where the atom has absorbed a photon and excited an electron to a higher energy state

- Why don't we see those atoms re-emit the same photon when they de-excite?

* Atoms WILL emit these photons again and electrons fall back to ground state, BUT photons will be scattered in all directions and so most will be lost from our sight

Solar Spectrum (as seen from Earth)



Where could the dark lines in the Solar spectrum be coming from?

A. Absorption in the Sun's atmosphere

B. Emission from the Sun's atmosphere

C. Absorption in the interior of the Sun

D. Emission from the interior of the Sun

Where could the dark lines in the Solar spectrum be coming from?

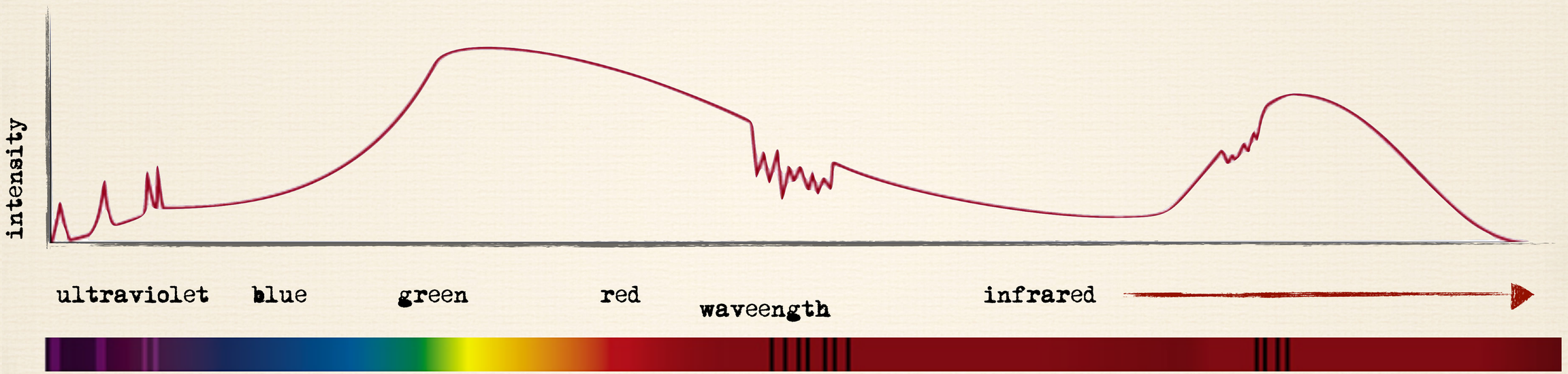
A. Absorption in the Sun's atmosphere

B. Emission from the Sun's atmosphere

C. Absorption in the interior of the Sun

D. Emission from the interior of the Sun

What is this object?



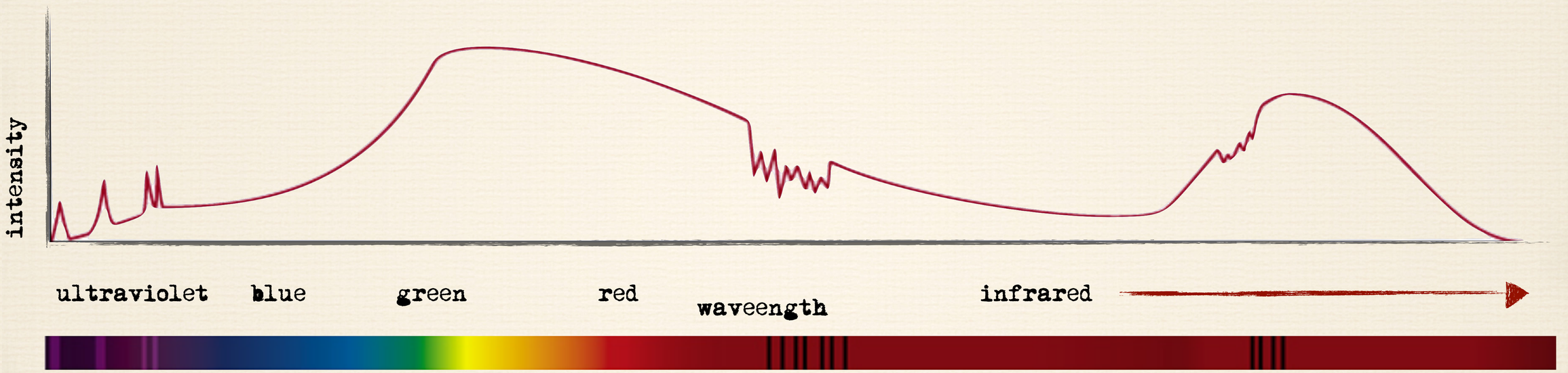
A. Venus

B. Mars

C. The Moon

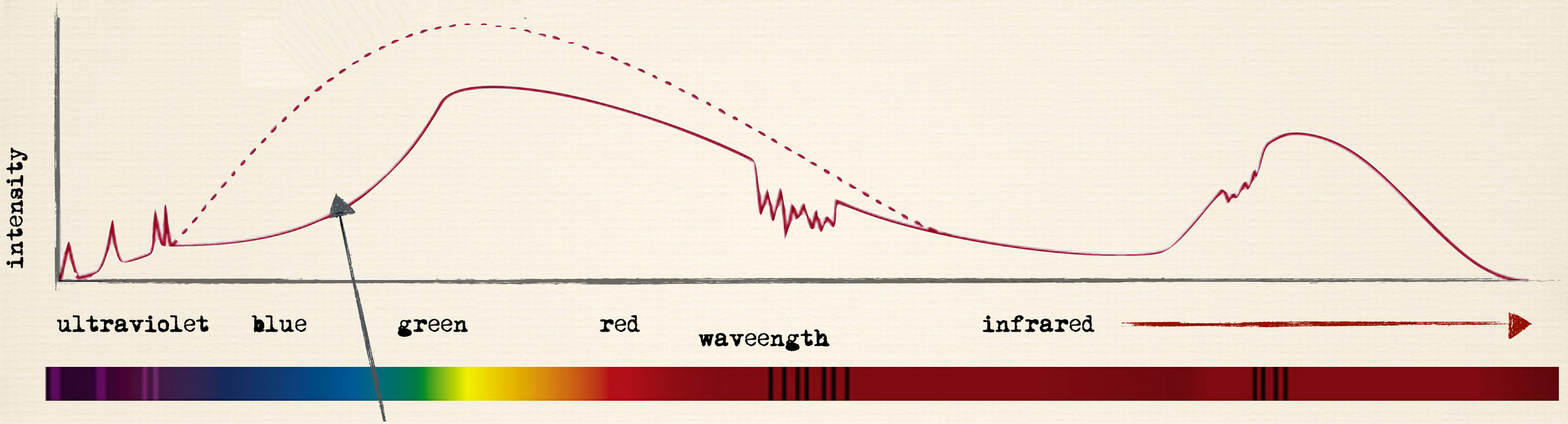
D. Pluto

What is this object?



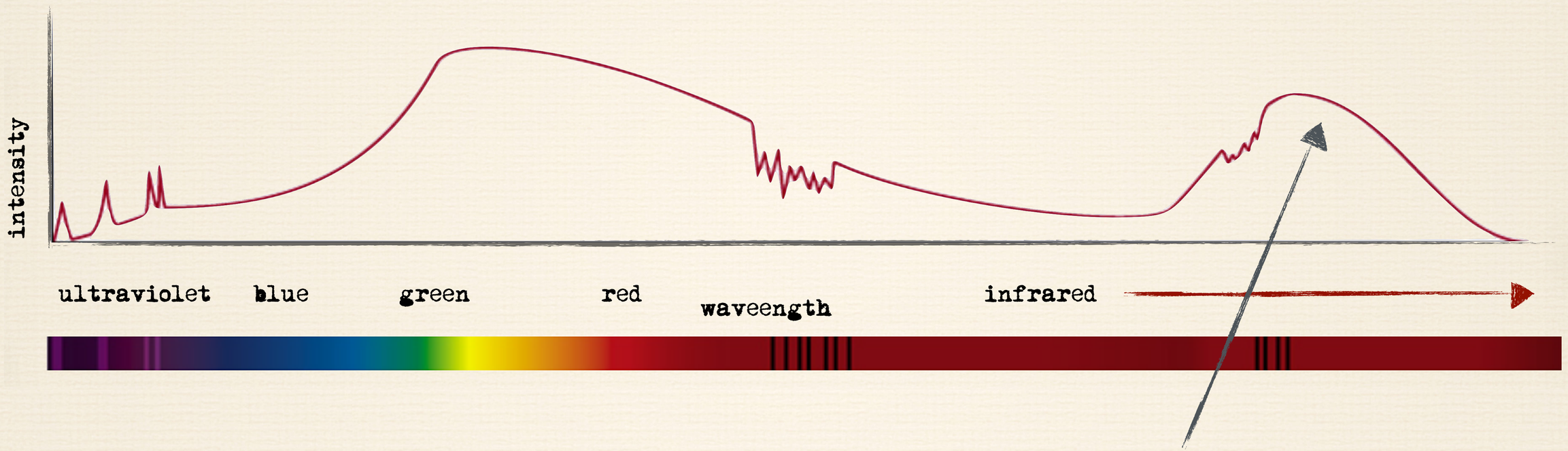
Let's use its spectral information to determine what it is

What is this object?



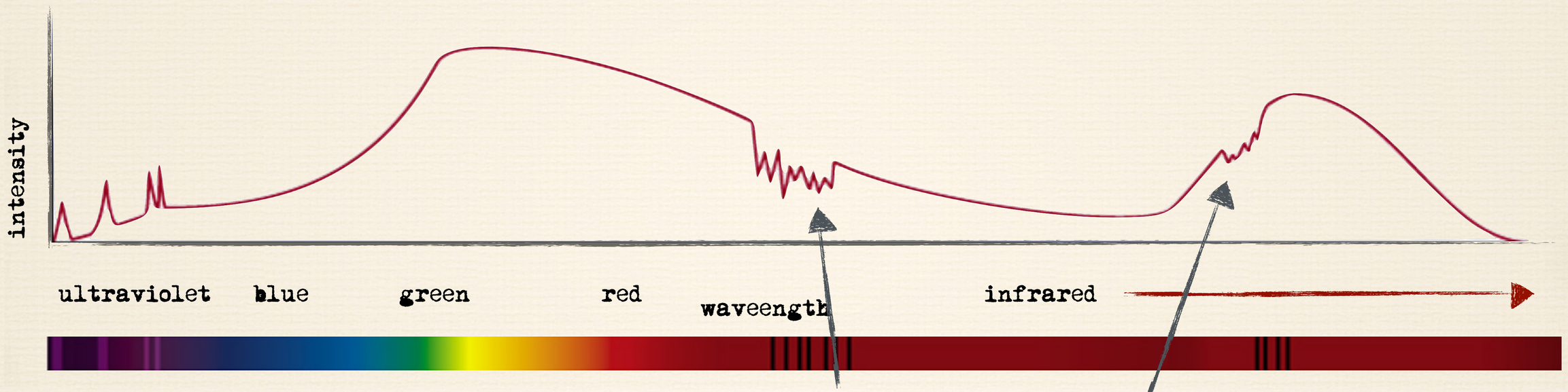
Reflected Sunlight: Continuous spectrum of visible light is like the Sun except that some of the blue light has been absorbed - object must look red

What is this object?



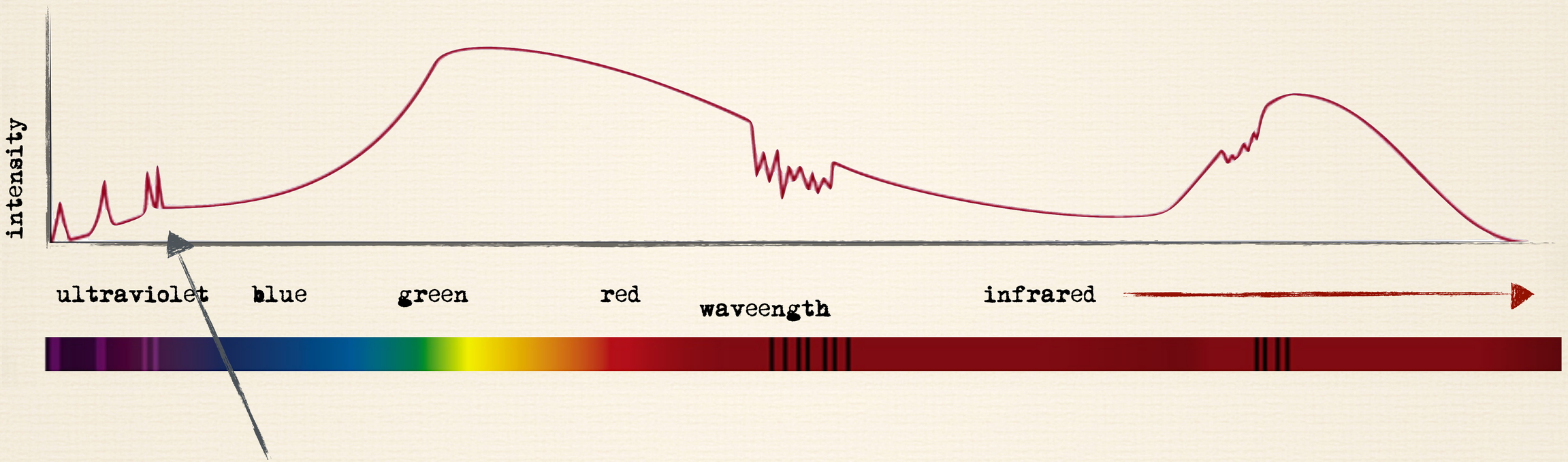
Thermal Radiation: Infrared spectrum peaks at a wavelength corresponding to a temperature of 225 K

What is this object?



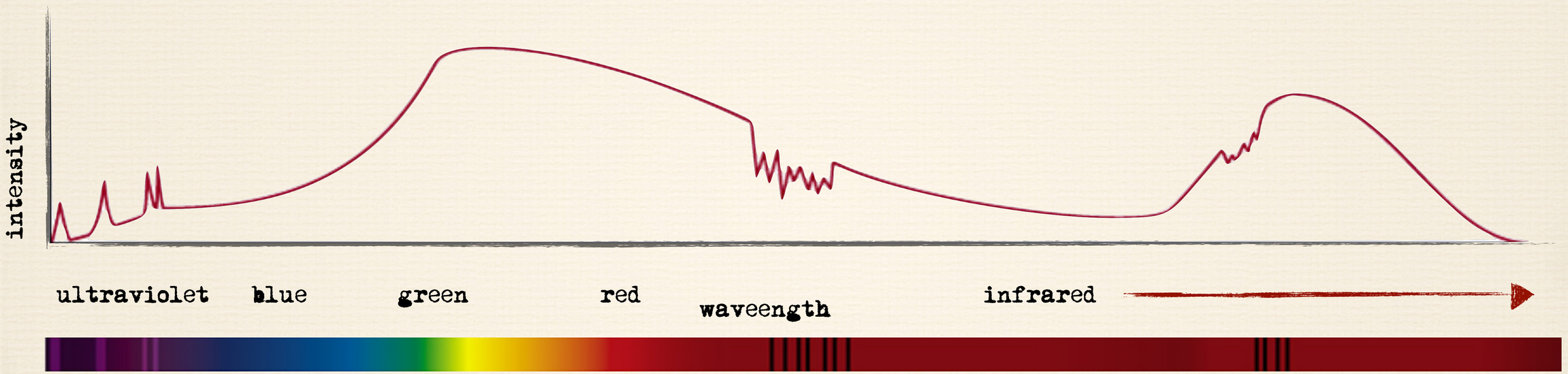
Carbon Dioxide: Absorption lines are the fingerprint of CO_2 in the atmosphere

What is this object?



Ultraviolet Emission Lines:
Indicate a hot upper atmosphere

What is this object?



B. Mars!

QUERY 16

Heated lithium atoms emit photons of light with an energy of 2.961×10^{-19} Joules

Calculate the frequency and wavelength of one of these photons, what is the color of the emitted light?

[Hint: h = 6.62×10^{-34} J s and c = 3×10^{8} m/s]

QUERY 16

Heated lithium atoms emit photons of light with an energy of 2.961×10^{-19} Joules

Calculate the frequency and wavelength of one of these photons, what is the color of the emitted light?

[Hint: $h = 6.62 \times 10^{-34}$ J s and $c = 3 \times 10^{8}$ m/s]

The frequency is ☛ $f = E/h = 4.469 \times 10^{14}$ Hz

The wavelength is ☛ $\lambda = c/f = 6.709 \times 10^{-7}$ m

This corresponds to red light