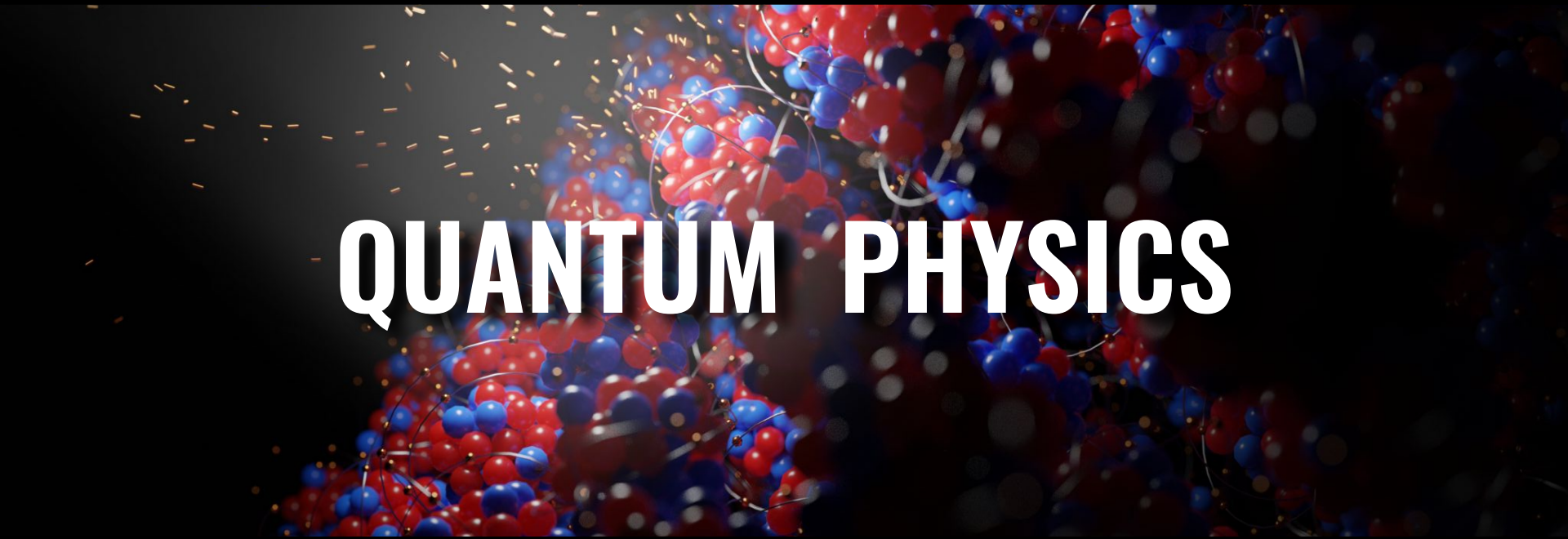
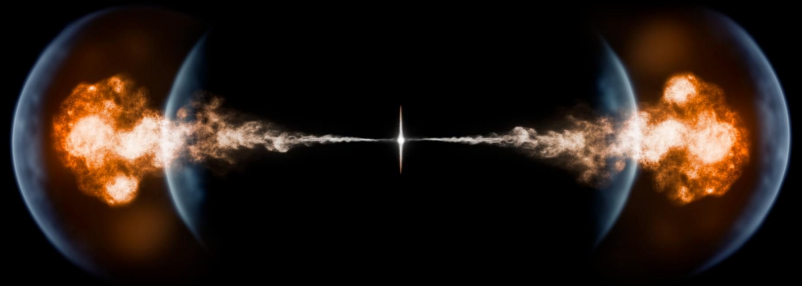
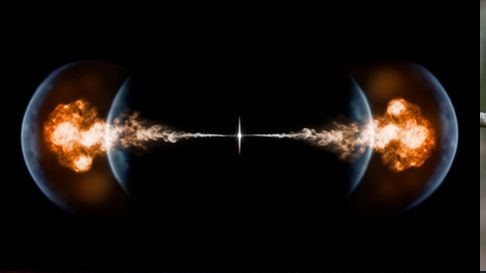

QUANTUM PHYSICS

Ben Amend

Ph.D. Candidate, Department of Physics & Astronomy

*I study **gamma-ray bursts** - the brightest explosions in the universe - using computer simulations.*

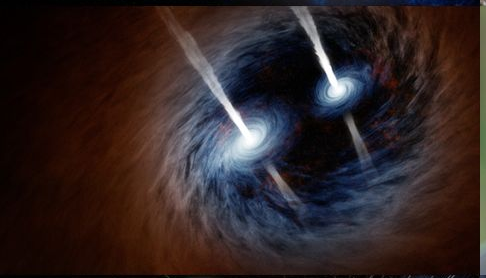
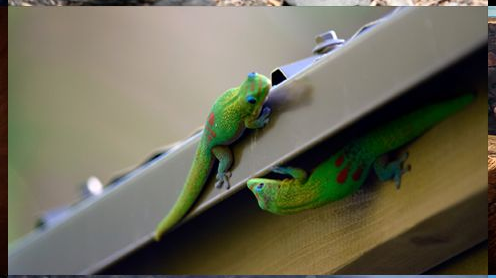


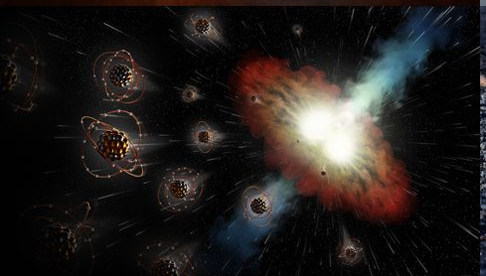






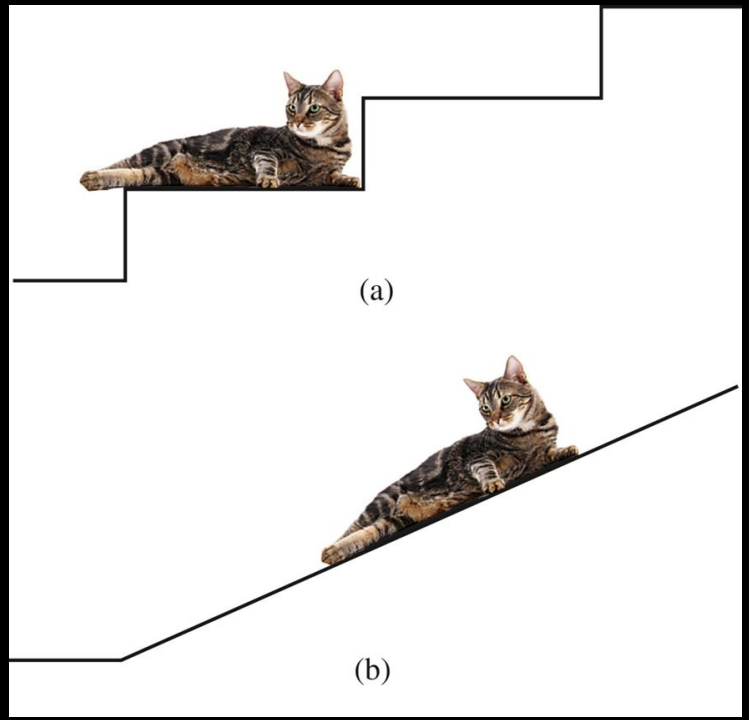



Quantum Physics

What do you think about when you hear the word ‘quantum’?



‘Quantum’ means a **discrete chunk** of something.

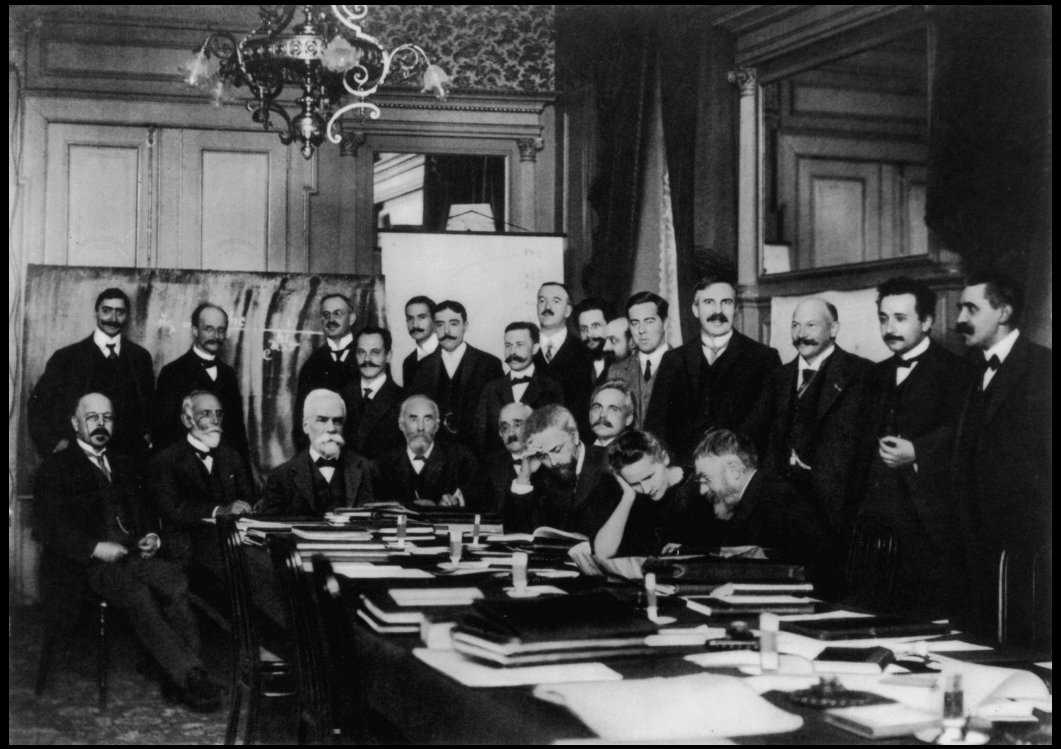
Which of these light switches is quantized?

"Toggle Light Switch" by Funpika is licensed under CC BY-SA 3.0 US. "Electric residential lighting dimmer switch" by BrokenSphere is licensed under CC BY-SA 3.0.

CLICKER QUESTION 1

Which of the following is **quantized** ?

A.) The speed of a car on the highway
B.) The number of eggs in a carton
C.) The temperature of a cup of coffee
D.) The angle of an open door



"1911 Solvay Conference" by Benjamin Couprie, Public Domain.

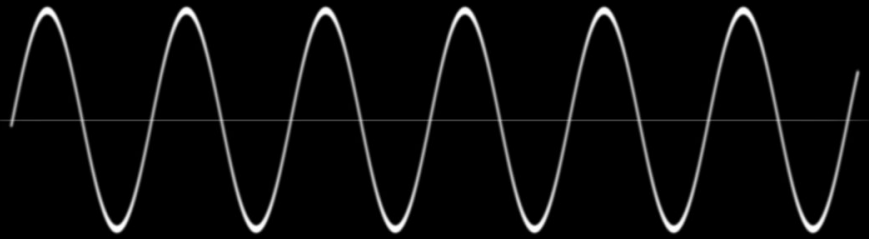
Unsolved Problems:

- The Photoelectric Effect
- Blackbody Radiation
- Atomic Spectra

The Photoelectric Effect

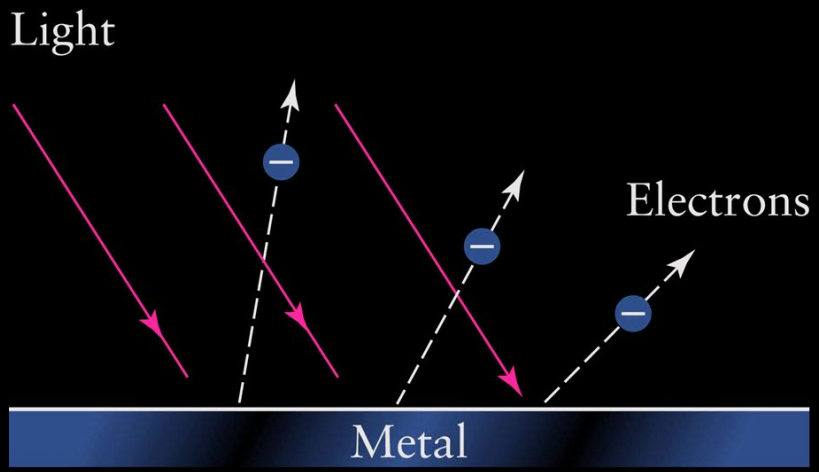
From earlier lectures, you've learned that light is _____.

Property of Waves:



Greater amplitude means _____ energy.

Smaller amplitude means _____ energy.

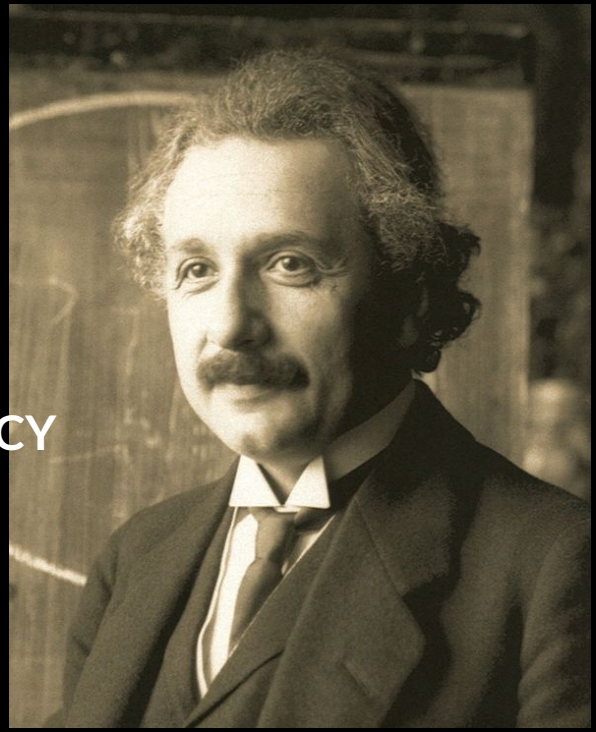


Observational Fact: Shining light on some metals knocks electrons loose

PhET Simulation

The **energy** of **light** depends on its **_____Frequency (COLOR)_____**.

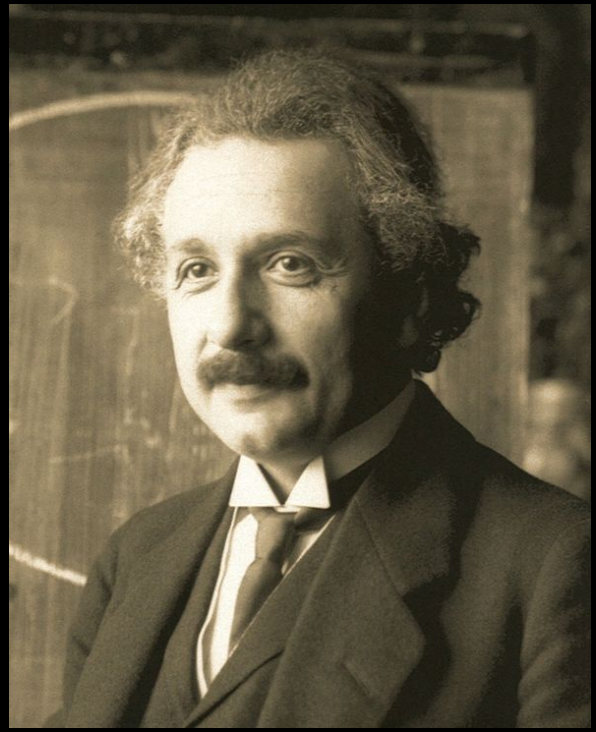
- Light is ____**quantized**_____, not continuous
- The quanta are **particles** called **photons**
- The ENERGY of a **photon** depends on its **FREQUENCY**



Albert Einstein

E = h * f

E: _____
h: Planck's constant (**6.63 * 10^{-34} J s**)
f: _____



Albert Einstein

CLICKER QUESTION 2

What is the energy of a photon with a frequency of 5×10^{14} Hz? (Remember that $h = 6.63 \times 10^{-34}$ J s)

A.) 0 J
B.) 7.54×10^{47} J
C.) 33.15 J
D.) 3.32×10^{-19} J

$$1\ eV = 1.60 \times 10^{-19}\ J$$

CLICKER QUESTION 3

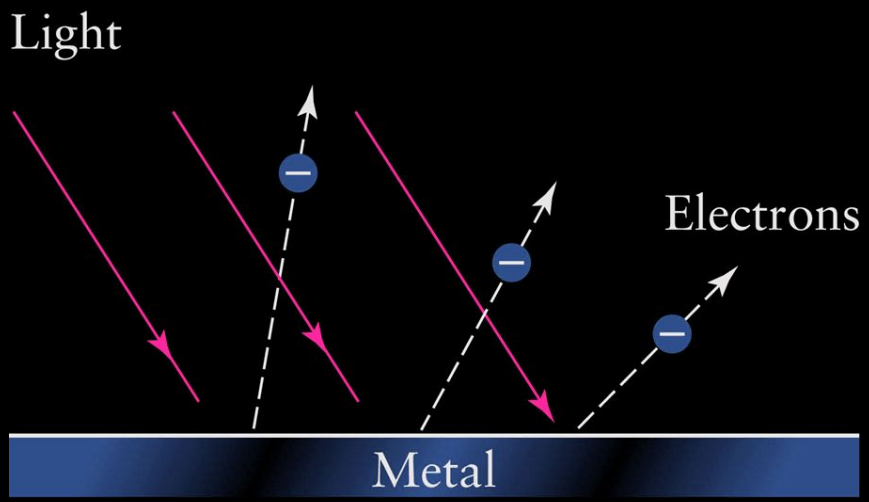
What is 3.32×10^{-19} J in units of eV? (Remember that 1 eV = 1.60×10^{-19} J)

A.) 5.31×10^{-38} eV
B.) 2.08 eV
C.) 5.31 eV
D.) 13.61 eV

But isn’t light a wave?

Yes (ish)

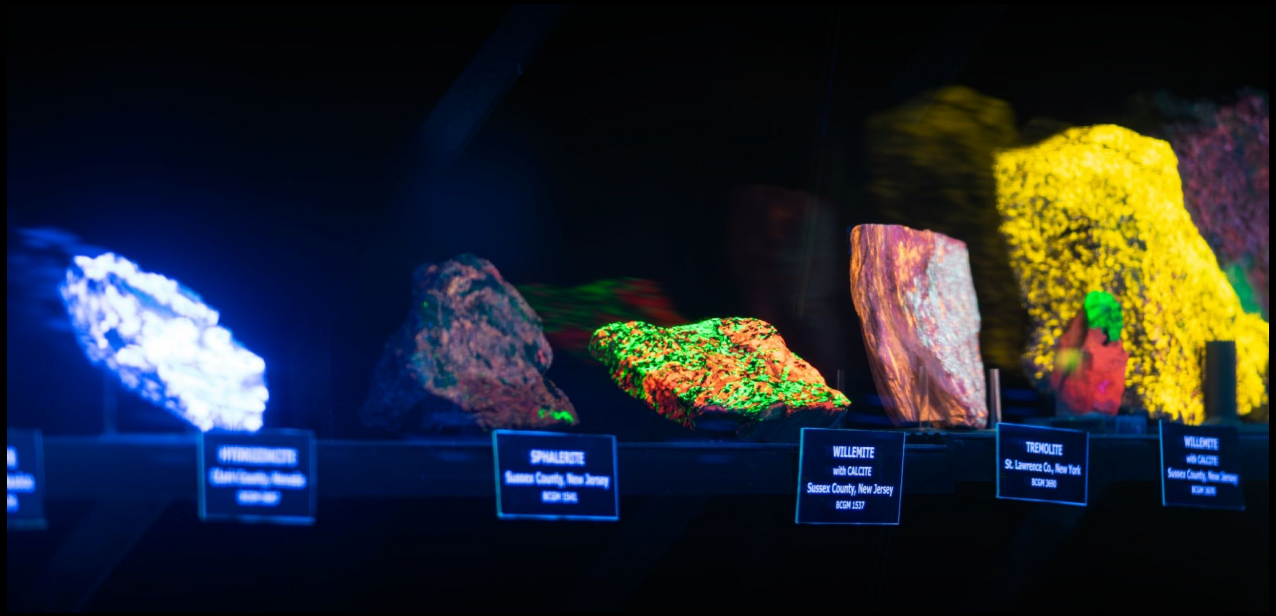
Light exhibits _____. This means it can act as a _____ or a _____ depending on the experimental circumstances.



What devices harness the photoelectric effect to turn light into electrical signals?

- Solar panels
- Night-vision goggles
- Automatic door sensors
- Radiation detectors
- Cameras

_____ is when an electron gains energy from an incoming photon, but not enough to be dislodged, and later loses this energy by **emitting its own photon**.

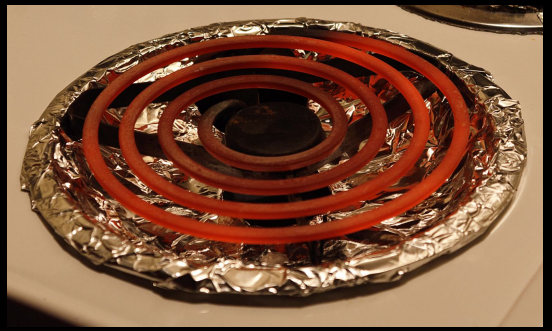


Blackbody Radiation

- **Thermal Radiation** is light that is emitted from hot objects
- **Blackbody radiation** is **thermal radiation** that comes from an object that aborbs all incident light .

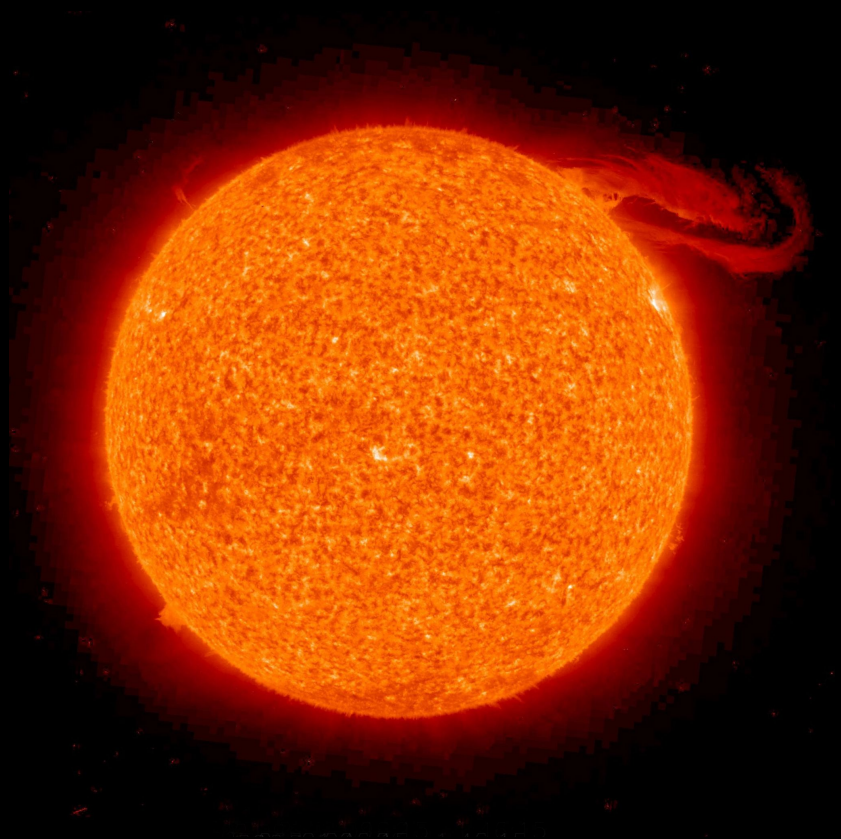
Some examples of blackbody radiation

"Partially working Toaster" by pfnicholls is licensed under CC BY-SA 4.0.



"Heating Element" by cactuscowboy is licensed under CC BY-SA 4.0.

"Light bulb in grandfather's lamp" by Lidija296 is licensed under CC BY-SA 4.0.



"The Sun" by NASA, Public Domain.

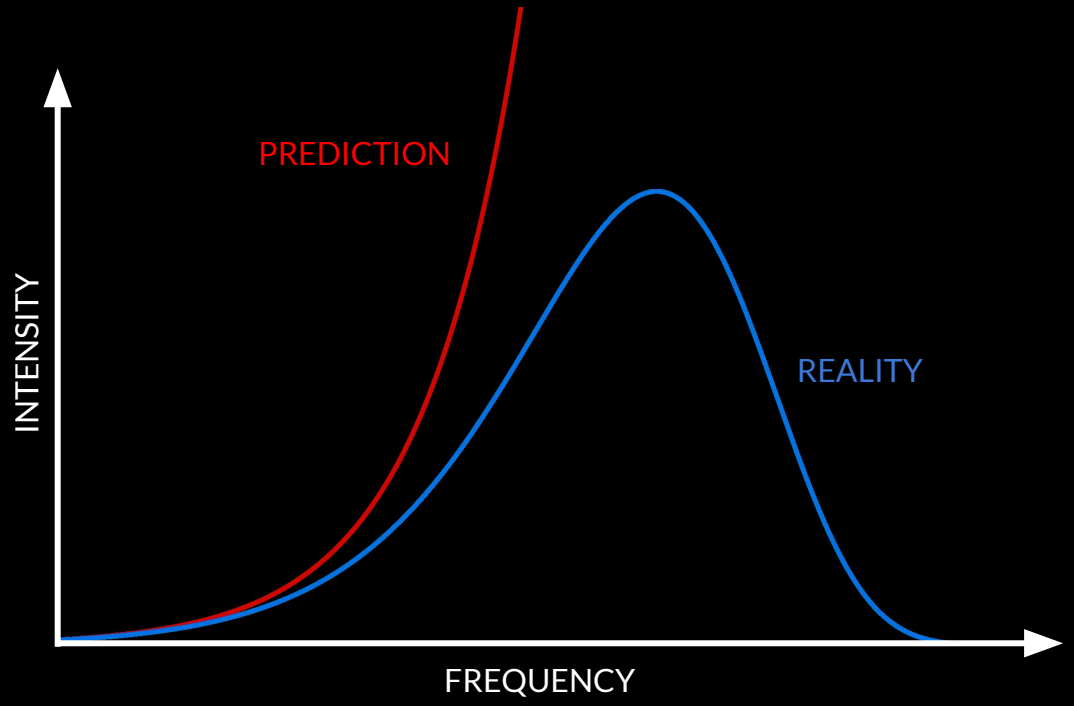
Nuclear fusion reactions in the cores of stars **generate heat** that causes the stars to **glow** in **visible light**

Living beings like us **generate heat** and **glow** in **infrared** light

"Covent Garden, London, in Thermal Infrared" by David Skinner is licensed under CC BY 2.0.

cly
@sh8rks

does the red mean the fish is still raw??? should i cook it more??

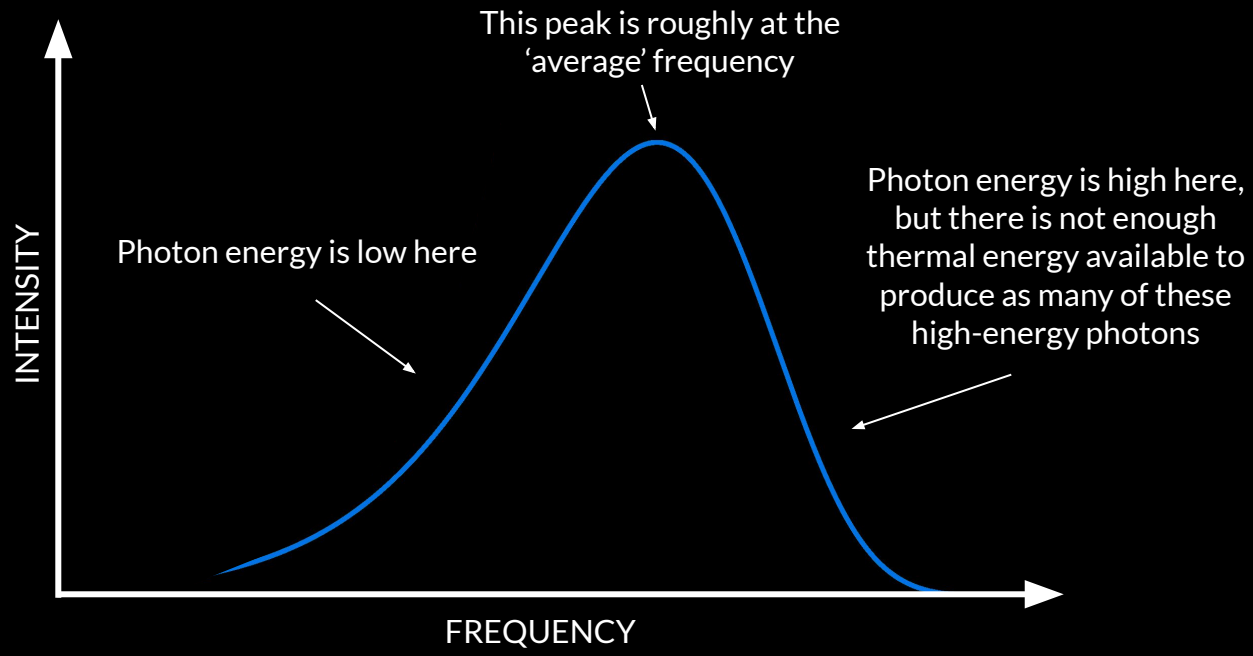


Predictions from physicists at the time were that the **intensity** of **light** would become **_Infinite_** for **high frequencies**

In reality, the **intensity** of **light** begins to **_Decrease_** after a **certain frequency**.

Max Planck

- Energy is **not Continous** , but comes in **quanta**
- These quanta come in the form of **_photons**


This peak is roughly at the
‘average’ frequency
Photon energy is high here,
but there is not enough
thermal energy available to
produce as many of these
high-energy photons
Photon energy is low here
INTENSITY
FREQUENCY

Wien's Displacement Law: $\lambda_{max} = b / T$

λ_{max} **:** Wavelength where light is brightest (m)
b: Wien's displacement constant ($2.898 * 10^{-3}$ m * K)
T: Temperature (K)

We've been talking about frequency, not wavelength - but remember that you can always convert between the two:

$$c = \lambda * f$$

c: Speed of light ($3 * 10^8$ m/s)
λ: _____ (m)
f: _____ (Hz)

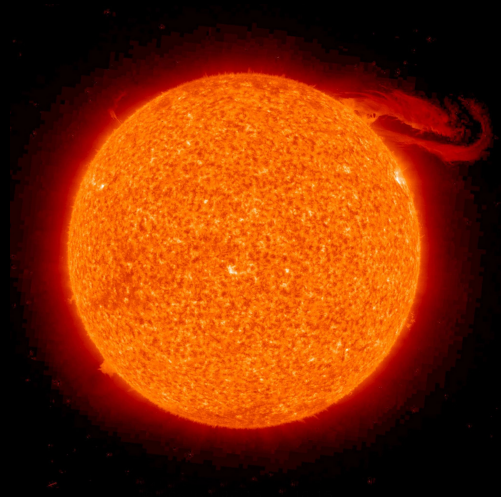
Example Problem:

The filament in an incandescent light bulb reaches a temperature of 3000 K. At what wavelength will the emission peak?

CLICKER QUESTION 4

Sunlight peaks at a wavelength of 502 nm (that's $5.02 * 10^{-7}$ m). If the sun is a perfect blackbody, what is its surface temperature?

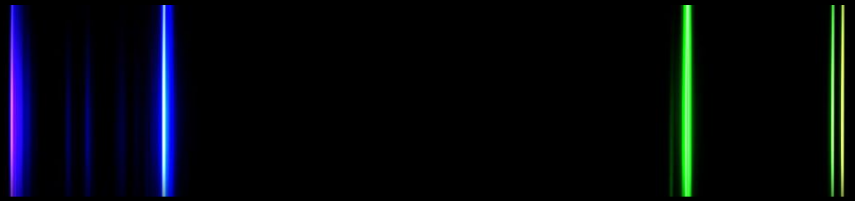
A.) 17322 K
B.) 9930 K
C.) 3000 K
D.) 5773 K



"The Sun" by NASA, Public Domain.

Atomic Spectra

- _____ is a combination of all colors in the visible spectrum
- This can be seen by splitting the light into its constituent wavelengths using a _____ or a _____



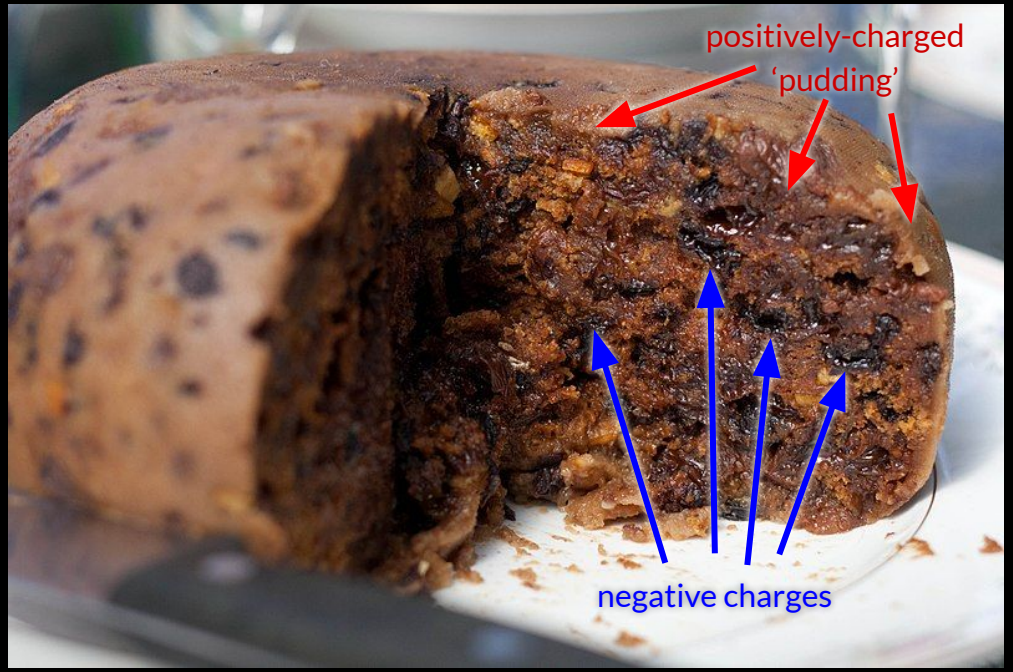
Heating gases causes them to **emit light**, but when this light is split apart, the result is a series of _____ - **not** a **smooth continuum**.

Why do we see **discrete lines** instead of a **continuum**? The answer involves the **structure** of _____.

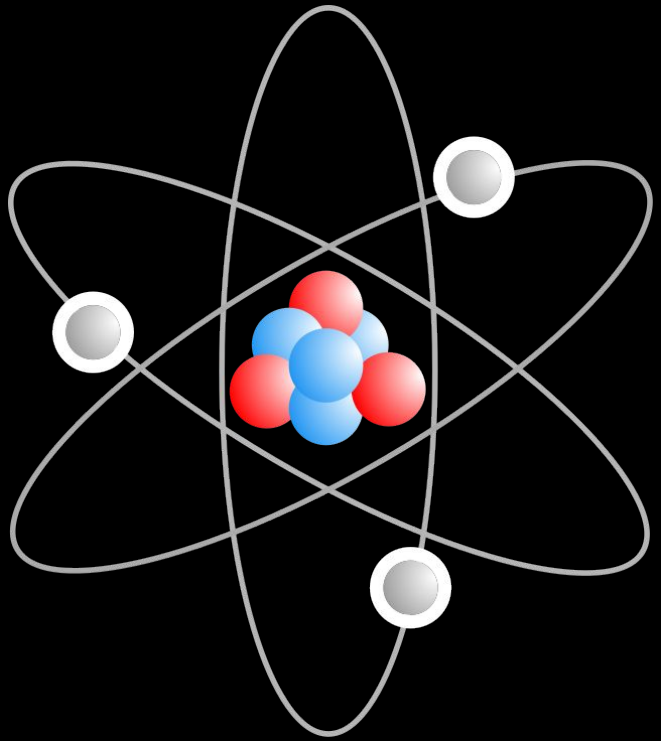
"Billiard balls with 8 ball in focus" by Anthony92931, licensed under CC BY-SA 3.0.

The **earliest models** of **atoms** represented them as _____, like tiny billiard balls.

In 1904, **J. J. Thomson** characterized **atoms** as a bunch of _____ **embedded** in a _____ **material**.



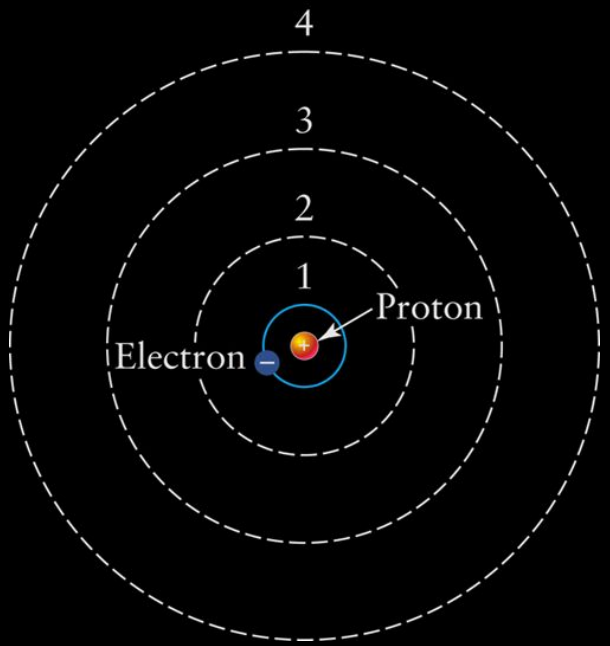
"Plum pudding" by Adambro, licensed under CC BY-SA 2.5.

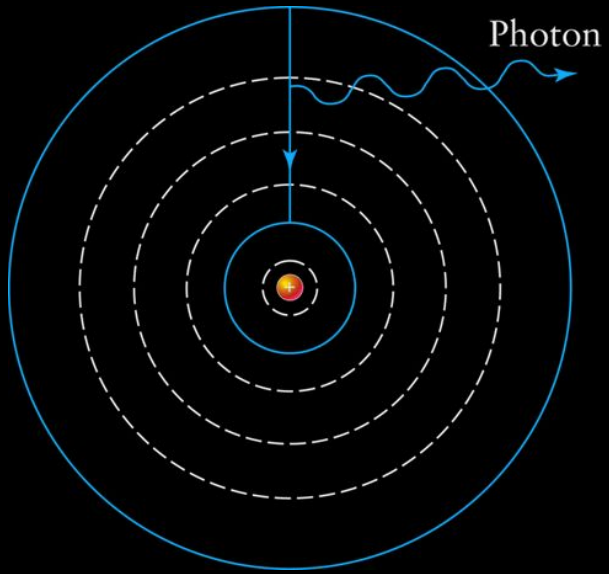


"Atomic structure of Lithium-7" by Greg Robson, licensed under CC BY-SA 2.5.

In 1911, **Ernest Rutherford** performed experiments that showed that **atoms** must **have** a dense, **positively-charged** _____ with _____ moving **around** it.

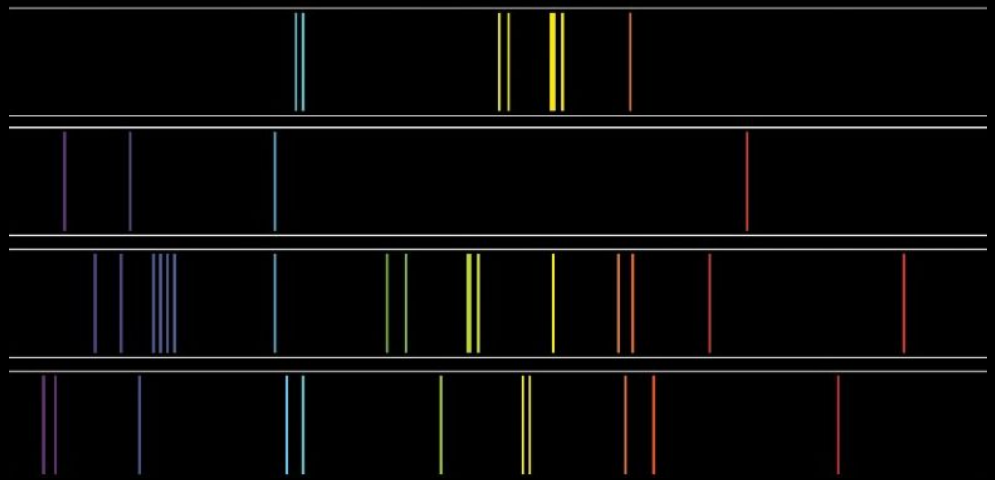
In 1913, **Niels Bohr** proposed that the **electrons can't** be just **anywhere** around the nucleus - they exist in **specific** _____ or **shells** around the **nucleus**.





When an **electron drops** from a **higher** _____ to a **lower** one, it **releases energy** in the form of a _____.

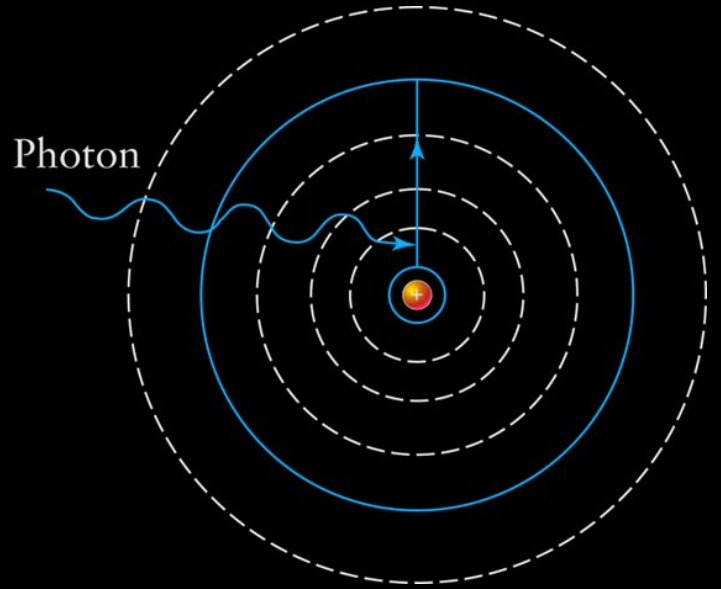
This is why heated gases produce discrete emission lines instead of a smooth continuum - the electrons that release the photons can only lose specific, discrete amounts of energy.

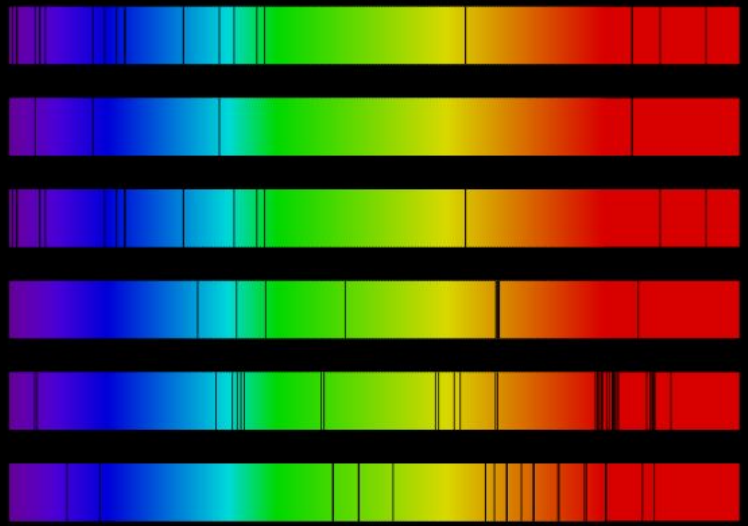


The collection of all colored lines that come from any given element is called its _____ .

Photons can also be _____ by atoms

This transfers energy to an electron, causing it to climb up to a higher _____





If light is shined **through** a gas, some of the photons will be absorbed by the atoms

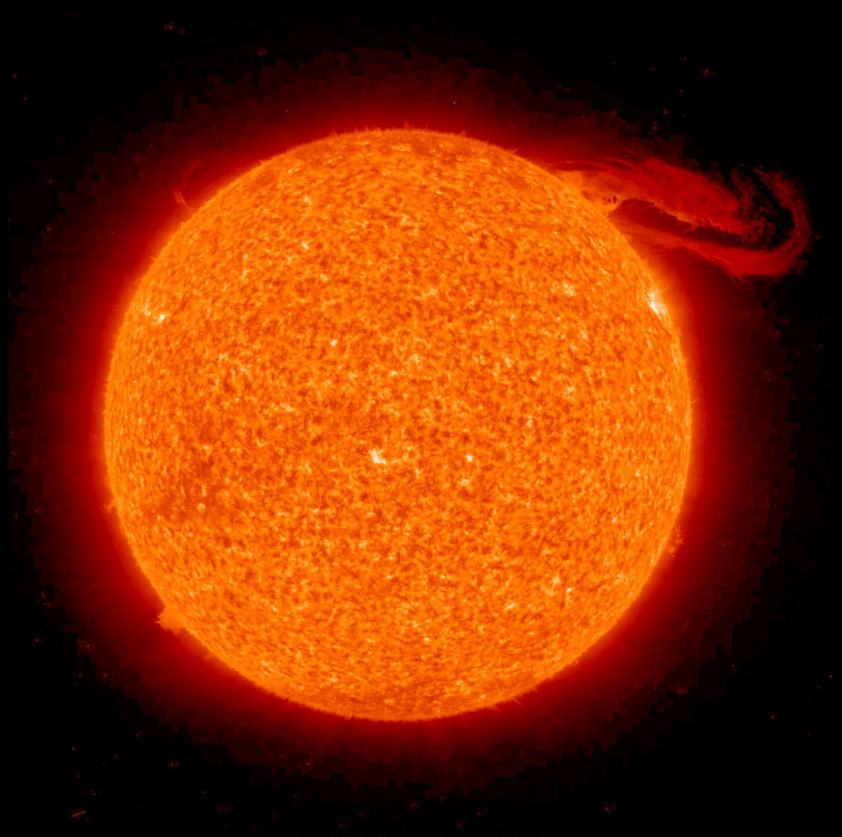
Instead of getting the full spectrum back, there are _____ where photons were absorbed

This is called an _____ **spectrum**

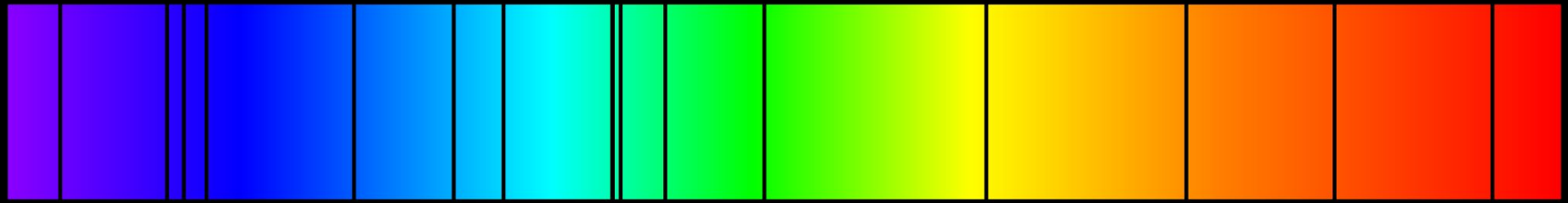
CLICKER QUESTION 5

What is the main difference between an emission spectrum and an absorption spectrum?

A.) An emission spectrum shows all colors, while an absorption spectrum shows only dark lines
B.) An emission spectrum shows the colors of light an atom **gives off**, while an absorption spectrum shows the colors it **takes in**
C.) An emission spectrum occurs only in solids, while an absorption spectrum occurs only in gases
D.) An emission spectrum is only for low-frequency light, while an absorption spectrum is only for high-frequency light



"The Sun" by NASA, Public Domain.



TOTAL SOLAR SPECTRUM

(More or less)

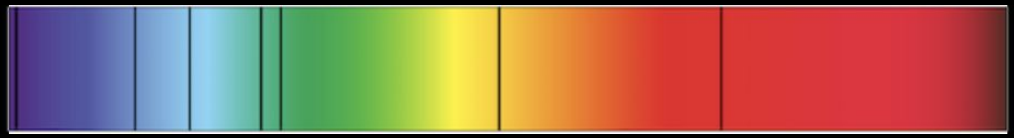
Identify the elements in the sun by lining up the absorption spectrum from each element to the total solar spectrum!

CLICKER QUESTION 6

Which two elements were you given that are **not** part of the solar spectrum?

A.) **Mg, O** (Magnesium, Oxygen)
B.) **Fe, H** (Iron, Hydrogen)
C.) **Ca, Na** (Calcium, Sodium)
D.) **Ar, Ne** (Argon, Neon)

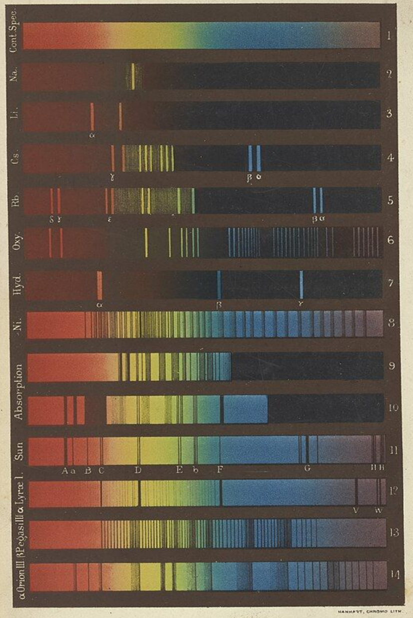
Helium



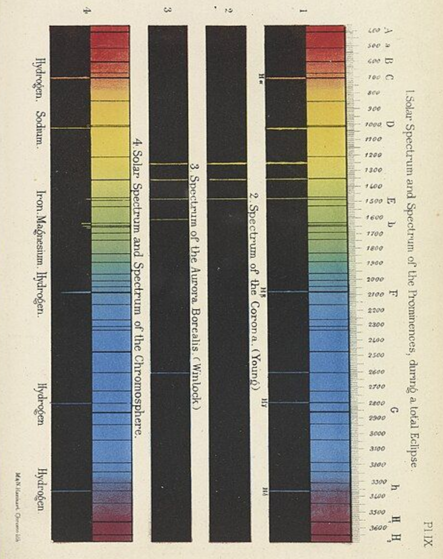
There is an element missing from the printouts you all have, and it’s this one - Helium.

Helium was first discovered in the solar spectrum by scientists doing what you just did - matching up all the lines to all known elements until only these ones remained.

TABLE OF SPECTRA. Pl I



HANHART, CHROMO LITH



CLICKER QUESTION 7

Why does a piece of metal change color as it gets hotter, glowing red, then orange, and eventually white?

A.) It's reflecting different colors from its surroundings
B.) As temperature increases, it emits more energy at higher frequencies
C.) The electrons inside are physically changing color
D.) It's changing its chemical composition

CLICKER QUESTION 8

In the photoelectric effect, which factor determines whether electrons are ejected from a material?

A.) The brightness of the light
B.) The total amount of light hitting the material
C.) The color (or frequency) of the light
D.) The angle at which the light hits the surface

CLICKER QUESTION 9

Why do heated gases produce a series of bright lines (an emission spectrum) instead of a continuous rainbow?

A.) The atoms randomly reflect some colors and absorb others
B.) Electrons can only jump between specific energy levels, emitting light at precise wavelengths
C.) The atoms block out most colors, leaving only a few behind
D.) The gas only allows high-energy blue light to pass through