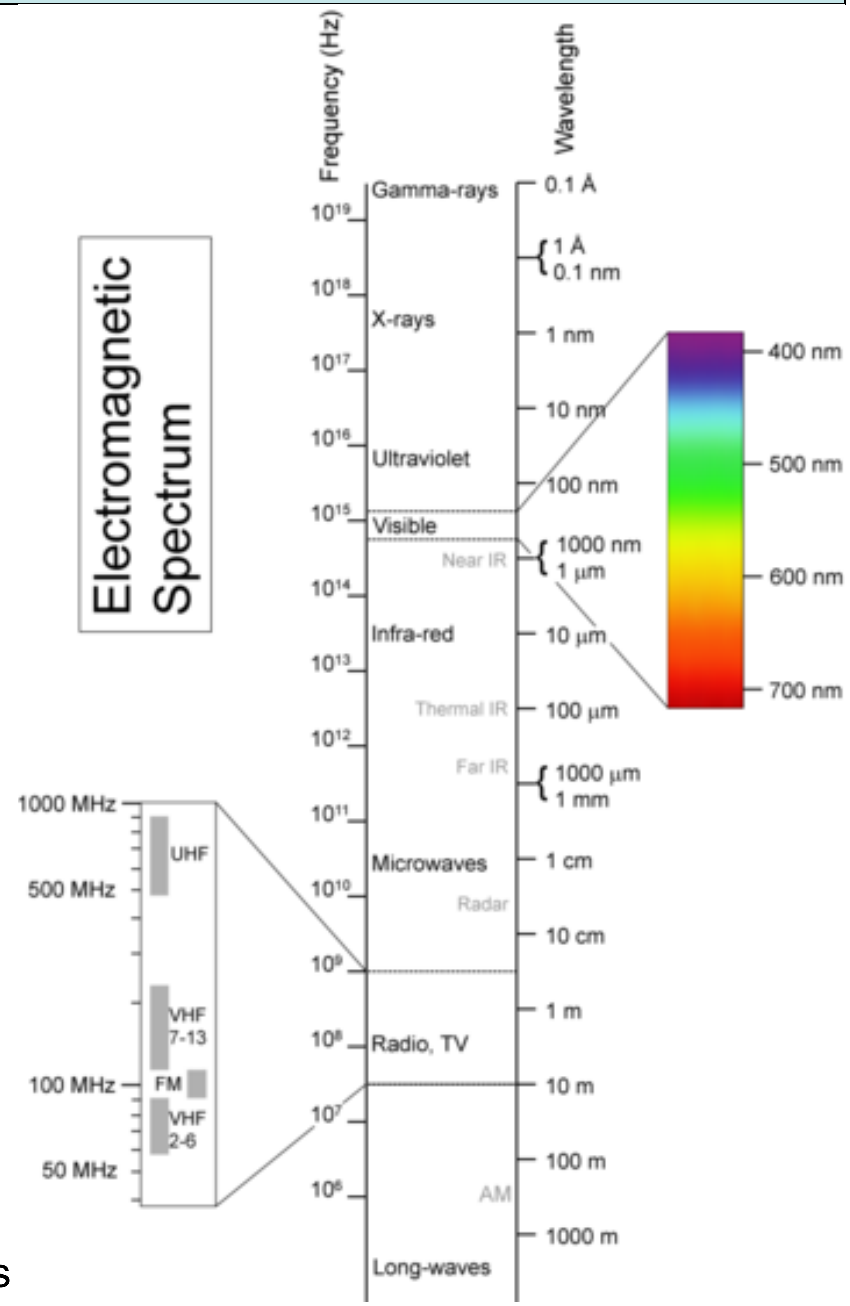
The atom cont. +Investigating EM radiation

Announcements:

- First midterm is 7:30pm on Sept 26, 2013
- Will post a past midterm exam from 2011 today.
- We are covering Chapter 3 today. (Started on Wednesday)

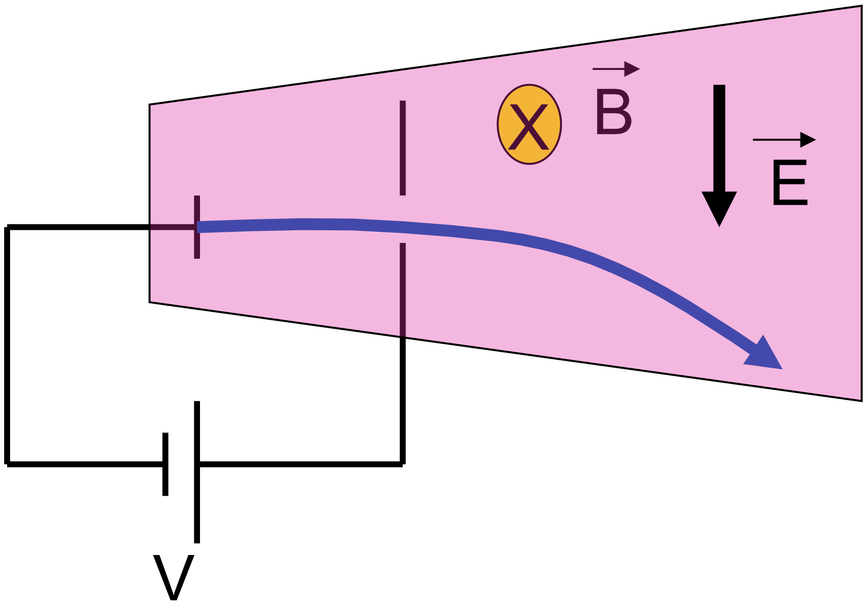


Measuring q/m for the electron (e/m)

The force by a magnetic field is perpendicular to the velocity so it causes centripetal acceleration.

$$\frac{mv^2}{r} = q\vec{v} \times \vec{B} \quad \Rightarrow \quad \frac{q}{m} = \frac{v}{rB}$$

If we knew the electron velocity we could find q/m.



Solution: Add an external downward E-field and adjust until the particle goes straight.

$$\vec{F}_{net} = q\vec{v} \times \vec{B} + q\vec{E} = 0$$

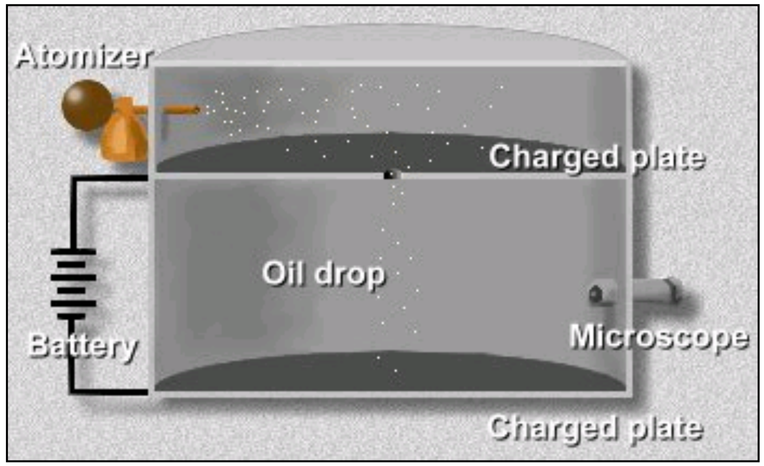
$$|\vec{v}| = |\vec{E}| / |\vec{B}|$$

Nobel Prize 1906, J.J. Thomson

Robert Millikan oil drop experiment (1911)

Thus, Thomson knew it was a negatively charged particle, and the e/m ratio (but not the charge or mass separately).

Enter the Millikan oil drop experiment in 1911



Oil is ionized by the atomizer. Can adjust the electric field so the drop is stationary. Then

$$F_{net} = q_{\text{drop}}E - m_{\text{drop}}g = 0$$

so $$q_{\text{drop}} = m_{\text{drop}}g / E$$

Find mass by measuring the terminal velocity in air.

Nobel Prize 1923

Drop 1: $Q_{drop1} = n_{drop1} \times e$
Drop 2: $Q_{drop2} = n_{drop2} \times e$
After many trials, one can determine the fundamental smallest charge $e = 1.6 \times 10^{-19}$ Coulombs.

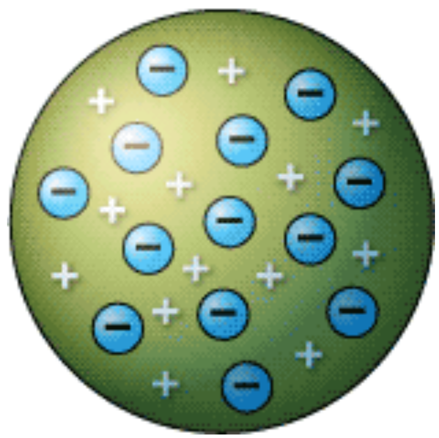
MMMmmmm, plum pudding (aka raisin cake)

What was known about atoms in 1900:

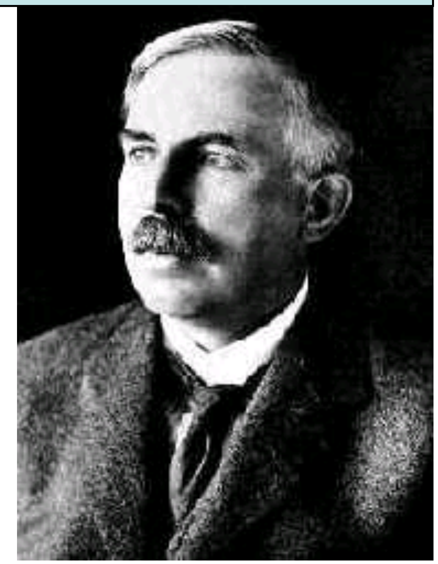
1. Atoms are heavy and electrically neutral
2. Electrons are light and negatively charged

With this knowledge and knowing that like charges repel and opposite charges attract, Thompson proposes the Plum Pudding model of the atom.

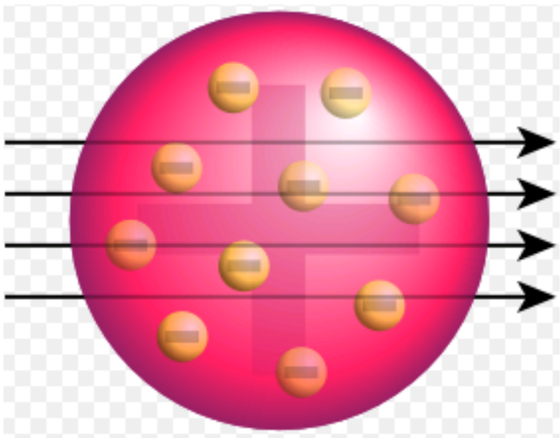
The electrons are like little negative raisins inside the heavy positive pudding.



Rutherford scattering experiment (1911)



In 1911, Rutherford (with his assistants Geiger and Marsden) did scattering experiments to test the Thomson Plum Pudding atom model.



Alpha particles are Helium nuclei (2 protons + 2 neutrons)

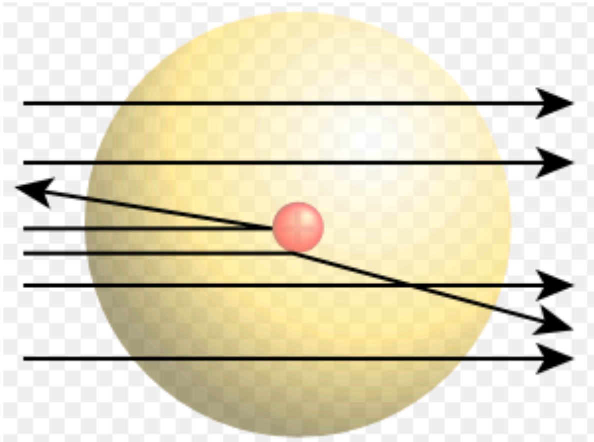
Rutherford sent alpha particles through very thin foils of metal.

Plum pudding model prediction: The alpha particles should bend very little since there is a balance of Coulomb forces between positive (pudding) and negative (plum) particles.

Most of the alpha particles behaved exactly that way…

Rutherford's solar system model of the atom

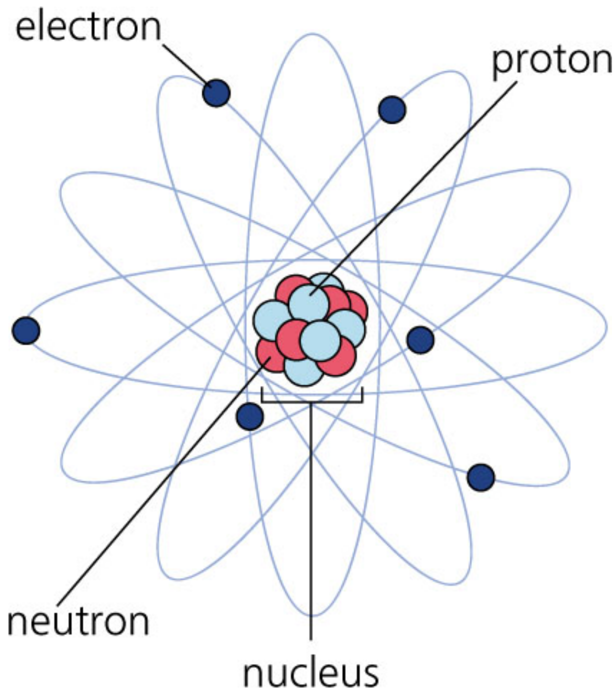
To his great surprise, some alpha particles scattered at very large angles, some almost straight back.



There must be a much larger electric field present. This led to the…

Rutherford (solar system) model:

1. The positive charges in the atom are concentrated in a nucleus that contains nearly all of the mass.
2. The negatively charged electrons surround the nucleus in large orbits.

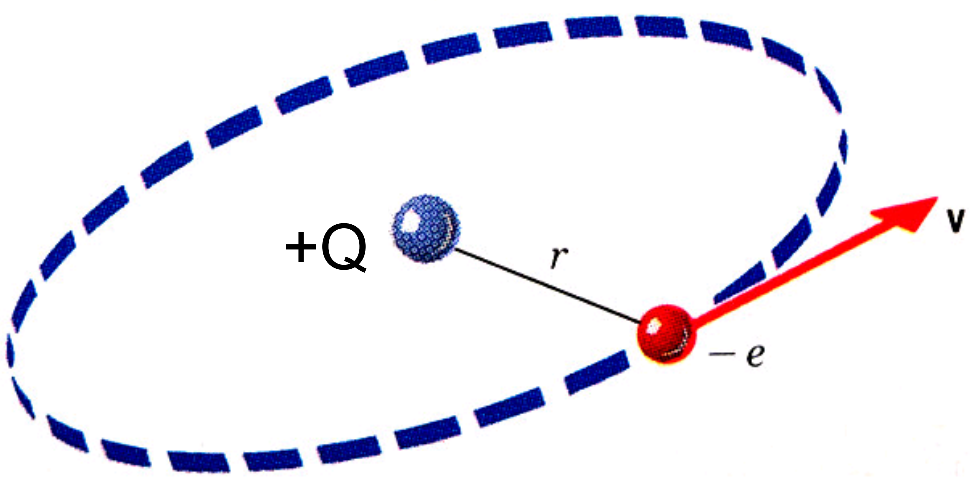


Rutherford's solar system model of the atom

Electrons are held in orbit around the positive nucleus by the Coulomb force.

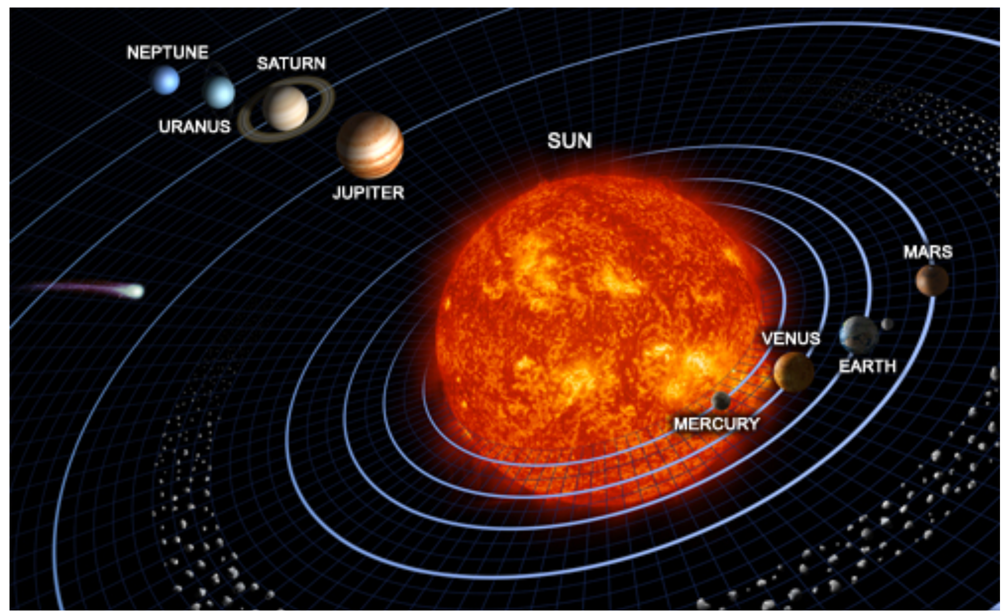
$$F = \frac{kq_1 q_2}{r^2} = \frac{mv^2}{r}$$

$$F = \frac{k(+Ze)(-e)}{r^2} = \frac{m_e v^2}{r}$$



Just like gravity acts on planets in the solar system:

$$F_G = \frac{GM_{\text{sun}} M_{\text{planet}}}{r^2} = \frac{m_{\text{planet}} v^2}{r}$$

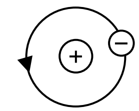


Clicker question 1	Set frequency to AD

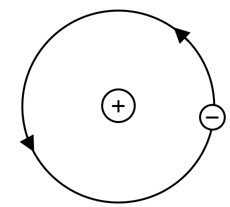
Which electron orbit has the smaller frequency?

A. Orbit 1 has the smaller frequency
B. Orbit 2 has the smaller frequency
C. Orbit 1 and 2 both have the same frequency
D. Impossible to determine from the information give.

Orbit 1



Orbit 2



Clicker question 1 | Set frequency to AD

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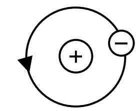
Orbit 1



A. Orbit 1 has the smaller frequency
B. Orbit 2 has the smaller frequency
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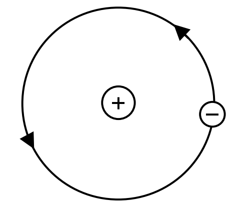
Orbit 2



Just as Mercury goes around the Sun faster than the Earth (88 days compared to 365 days).

Higher energy → larger radius orbit → longer period T → smaller frequency f

Lower energy → smaller radius orbit → shorter period T → larger frequency f

Issues with Rutherford's model of the atom

Classical electricity and magnetism theory combined with classical mechanics theory allow for these orbits.

That's the good news.

There were two problems, both of which come from classical EM theory which states that any charged particle that experiences acceleration must radiate electromagnetic waves.

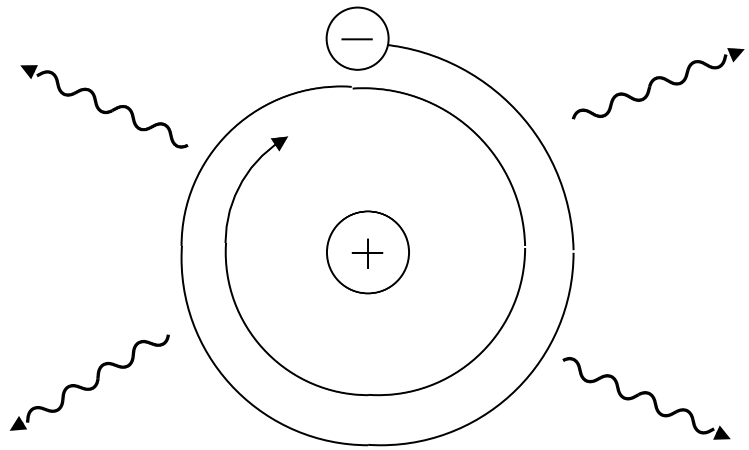
The frequency of this radiation is related to the frequency of the electron revolving around the nucleus.

Prediction 1: The electromagnetic radiation will cause the electron to lose energy and eventually fall into the nucleus.

Prediction 2: The light given off by the electron should be a continuous spectrum with all frequencies.

First problem – death spiral of the electron

Classically, an electron in an atom should radiate as it is accelerated around a circle. This causes it to lose energy and to spiral inward.



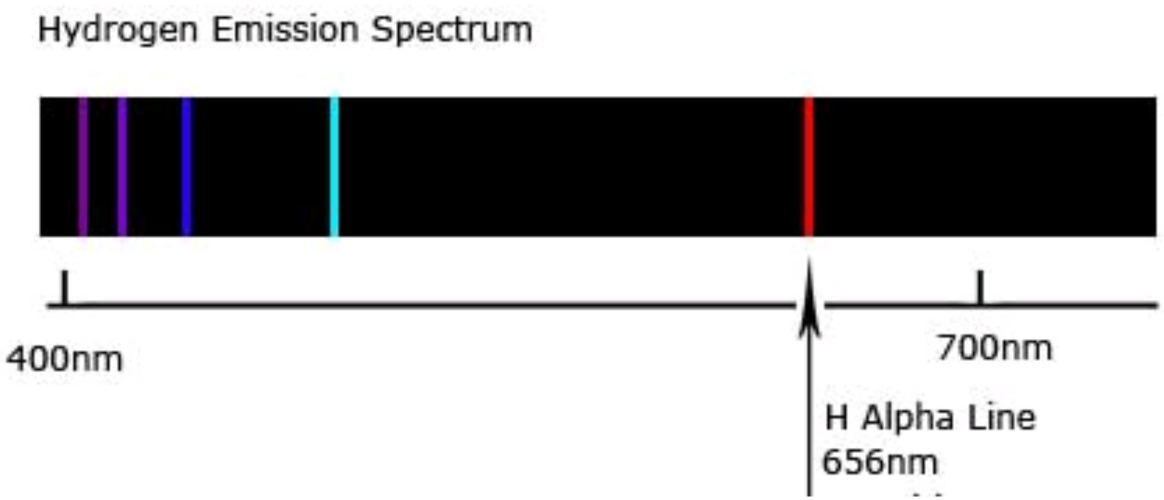
Calculations of the expected time for the electron to spiral in were done

The calculated time was 10^{-11} seconds.

Poof! There go all the atoms in the universe. That's not good!

2nd problem – atoms should emit continuous spectrum

Well before the model of the atom, people had heated up atomic matter and could study the emission of light.



Experimentally it was found that certain elements gave off light only at specific discrete wavelengths or frequencies.

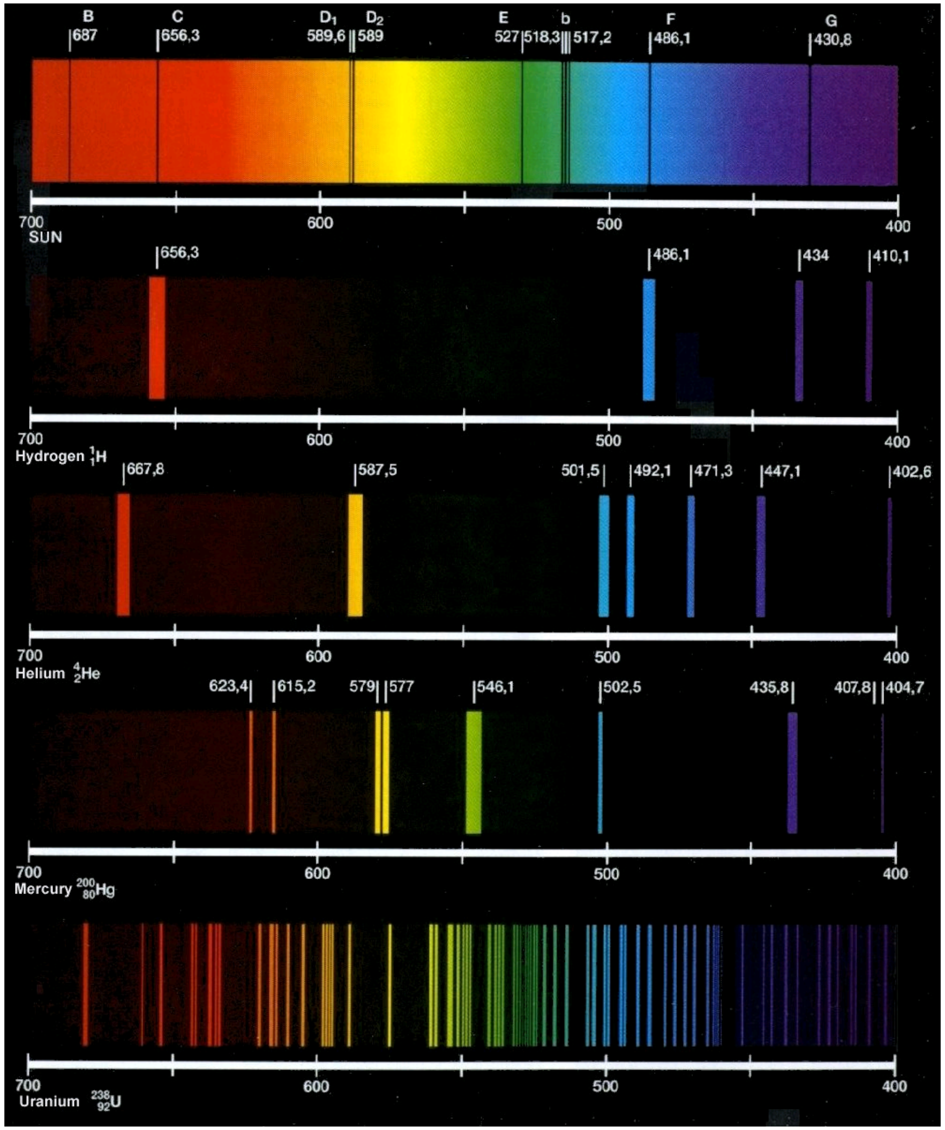
The electrons were *not* radiating a continuous spectrum.

Atomic spectra

Heated matter emits radiation.

Thermal random motion yields spectrum of wavelengths of EM radiation.

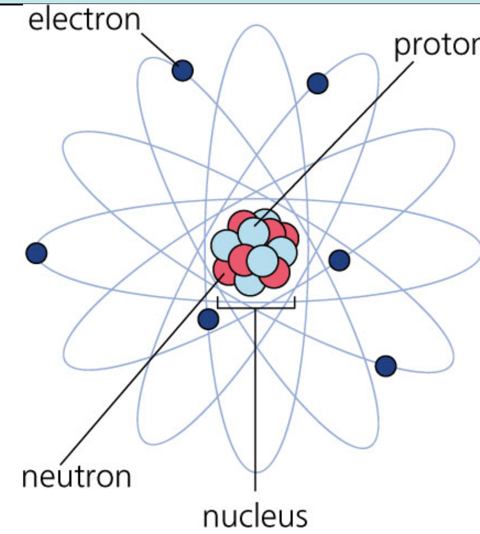
Spectra were observed in 1800's without knowing how or why?



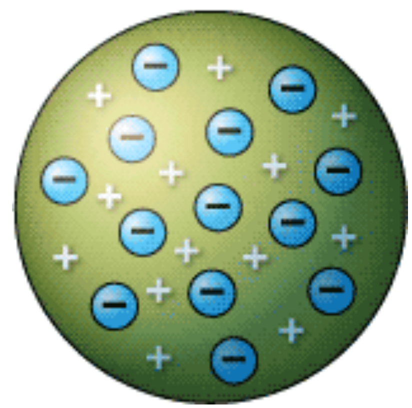
Final conundrum

The nucleus was full of positive particles which should all be repelling each other.

So what keeps the nucleus together?



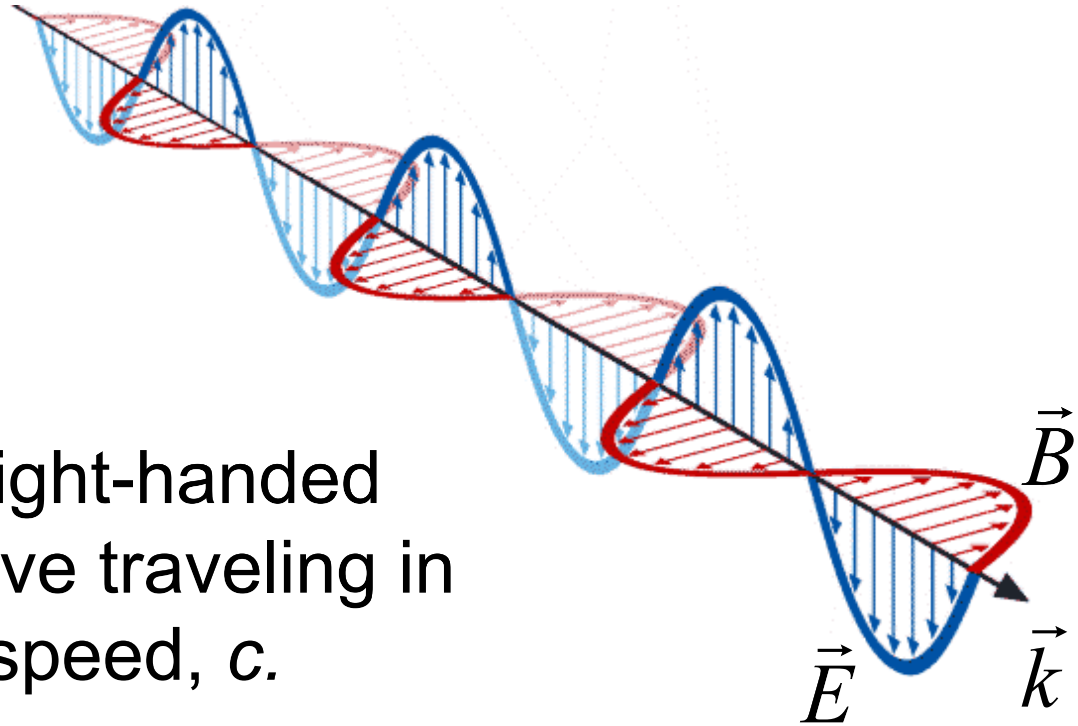
In the Plum Pudding model the positive and negative charges were distributed throughout the atom so this was not a problem.



We will discuss this later, but there must be a stronger force than the Coulomb force holding the nucleus together

Not being too original, physicists end up calling this the strong force; also called the nuclear force or strong nuclear force.

Maxwell's Equations describe EM radiation in vacuum:



E, *B*, and *k* form a 'right-handed system', with the wave traveling in the direction of *k* at speed, *c*.

Direction of travelling energy is given by the Poynting Vector = 1/4π E x B

Wave or Particle?

Question arises often throughout course:

- Is something a wave, a particle, or both?
- How do we know?
- When best to think of as a wave? as a particle?

In classical view of light, EM radiation is viewed as a wave (after lots of debate in 1600-1800's).

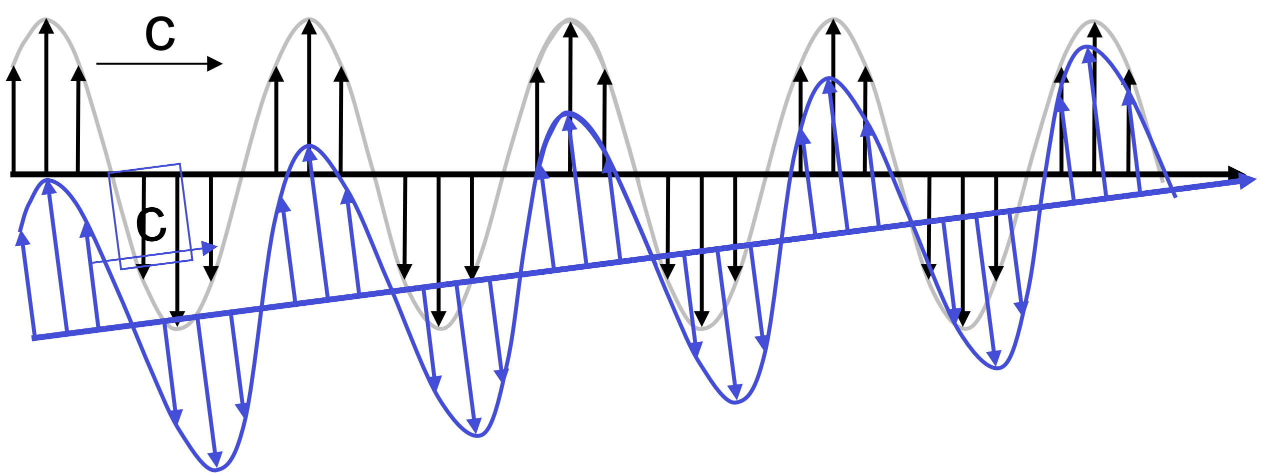
How would one decide it is a wave *experimentally*?

EM radiation is a wave

What is the most definitive observation we can make that tells us something is a wave?

Observe interference.

Constructive interference: (peaks are lined up and valleys are lined up)

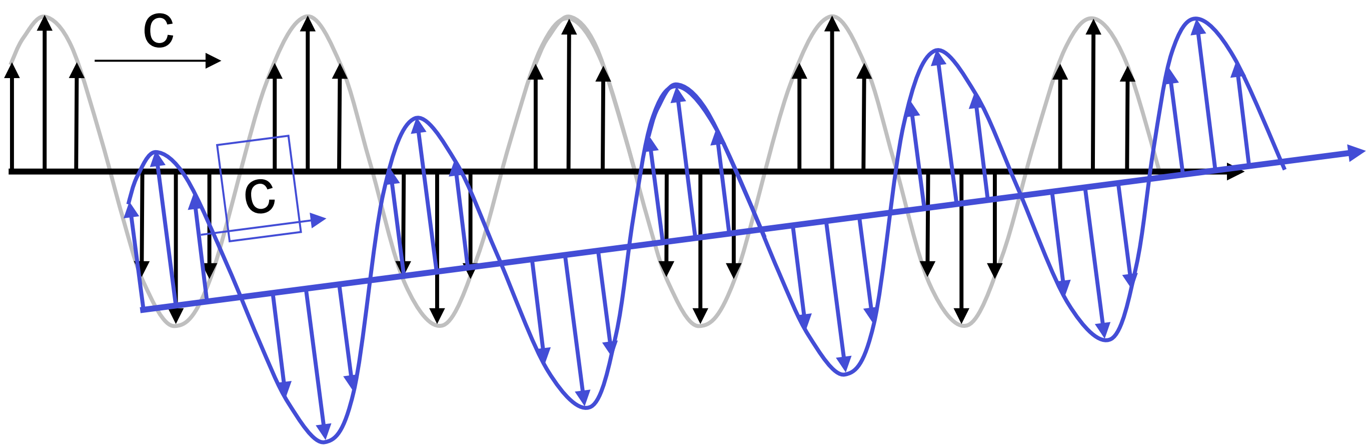


EM radiation is a wave

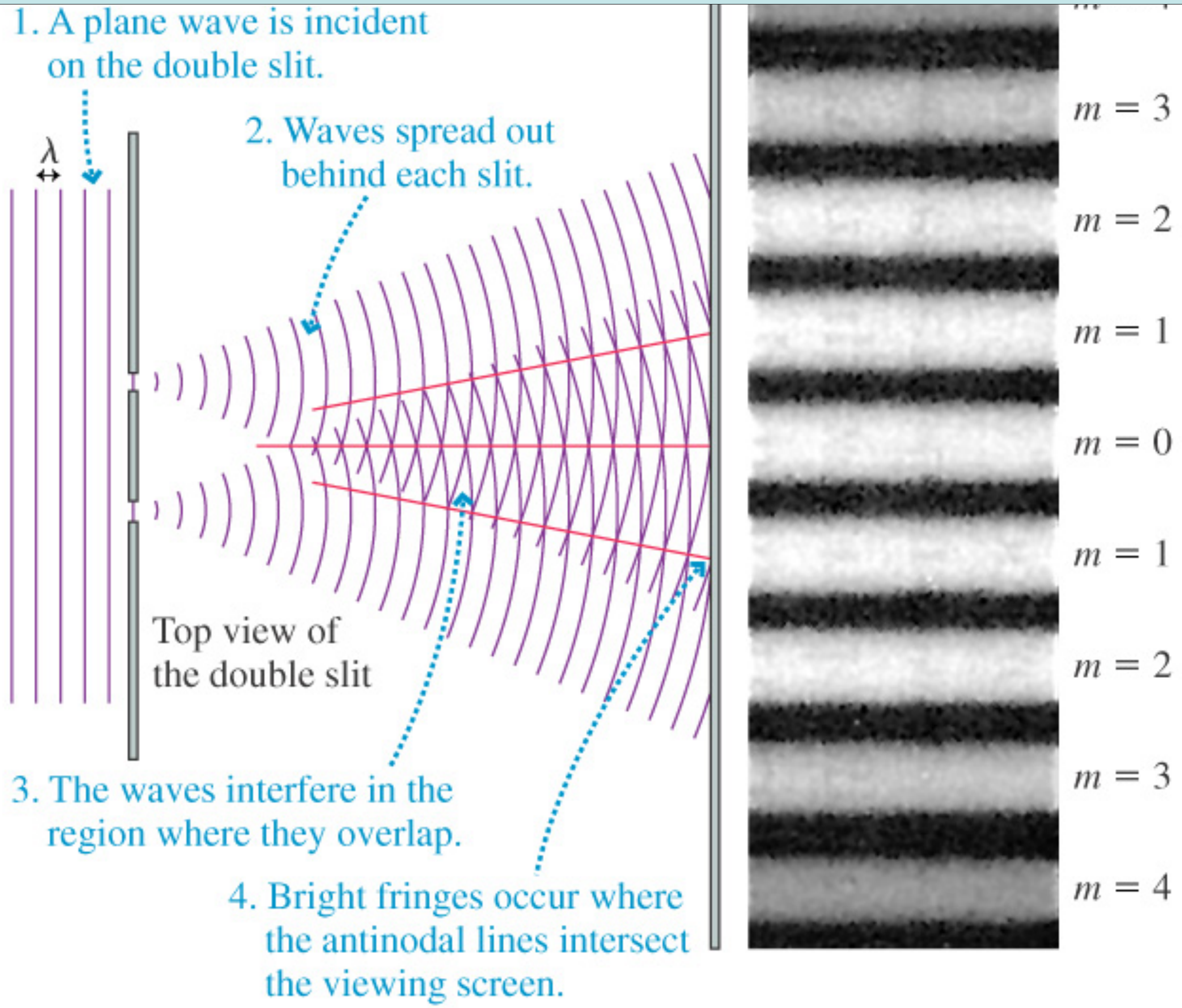
What is most definitive observation we can make that tells us something is a wave?

Observe interference.

Destructive interference: (peaks align with valleys – cancel)



Two slit interference

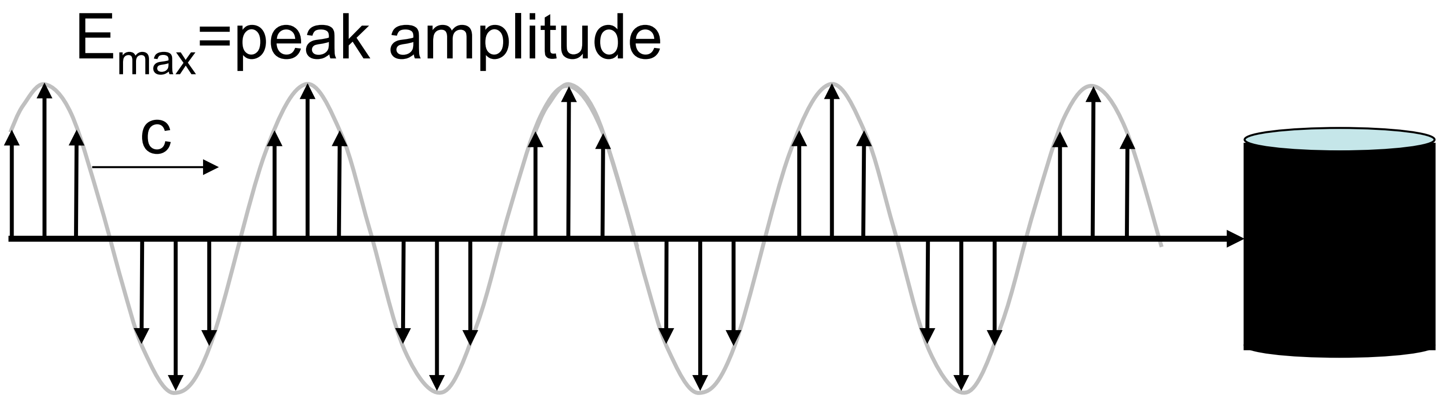


http://www.colorado.edu/phy

The observation of diffraction & interference convinced everyone that light was a wave.

Electromagnetic waves carry energy

Light shines on a black tank full of water.
How much energy is absorbed?



$$E(x,t) = E_{\max}\sin(ax - bt)$$ standard wave equation

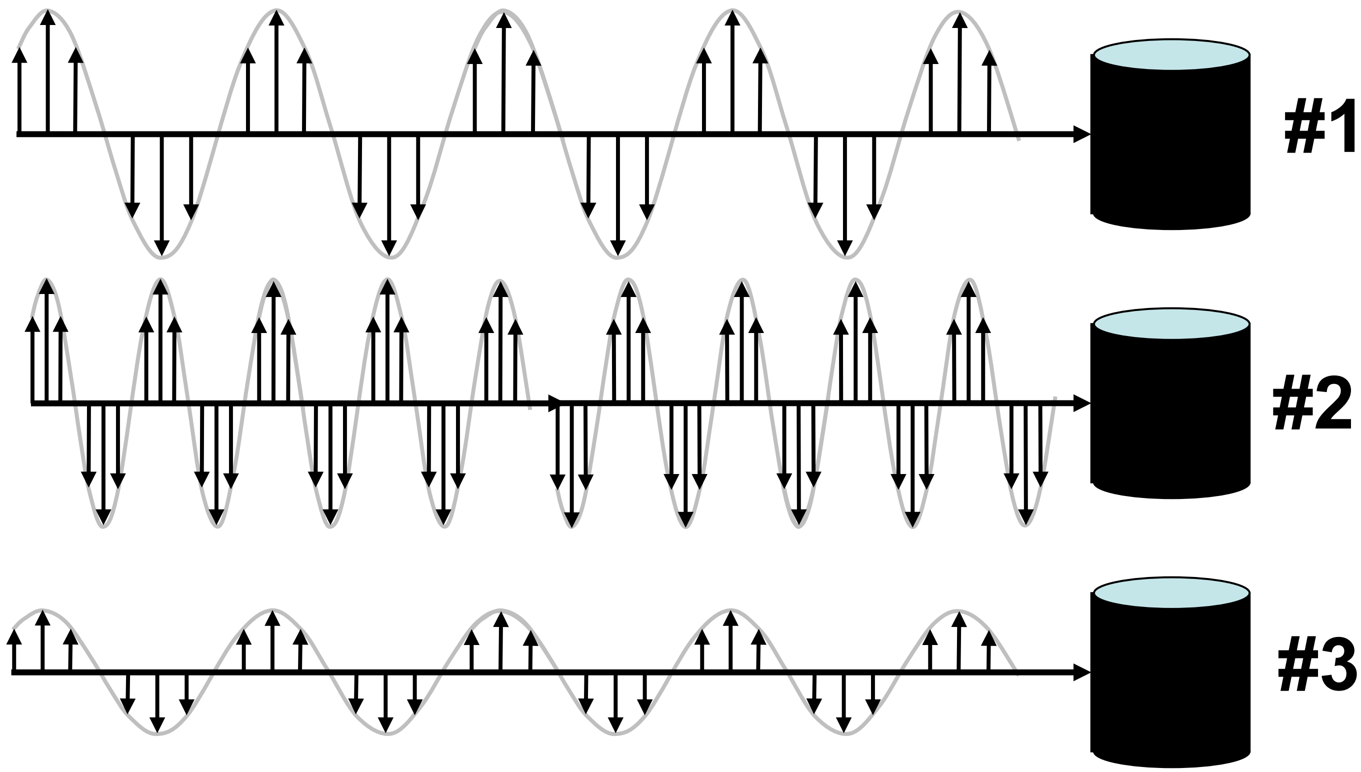
$$\text{Intensity} = \frac{\text{Power}}{\text{area}} = \frac{\text{energy/time}}{\text{area}} \propto E_{avg}^2 \propto E_{max}^2$$

EM waves carry energy proportional to the amplitude squared.

Clicker question 2 | Set frequency to AD

Which barrel will heat up the fastest?

A. 2>1>3
B. 1>2>3
C. 1=2>3
D. 1=3>2
E. 2>1=3



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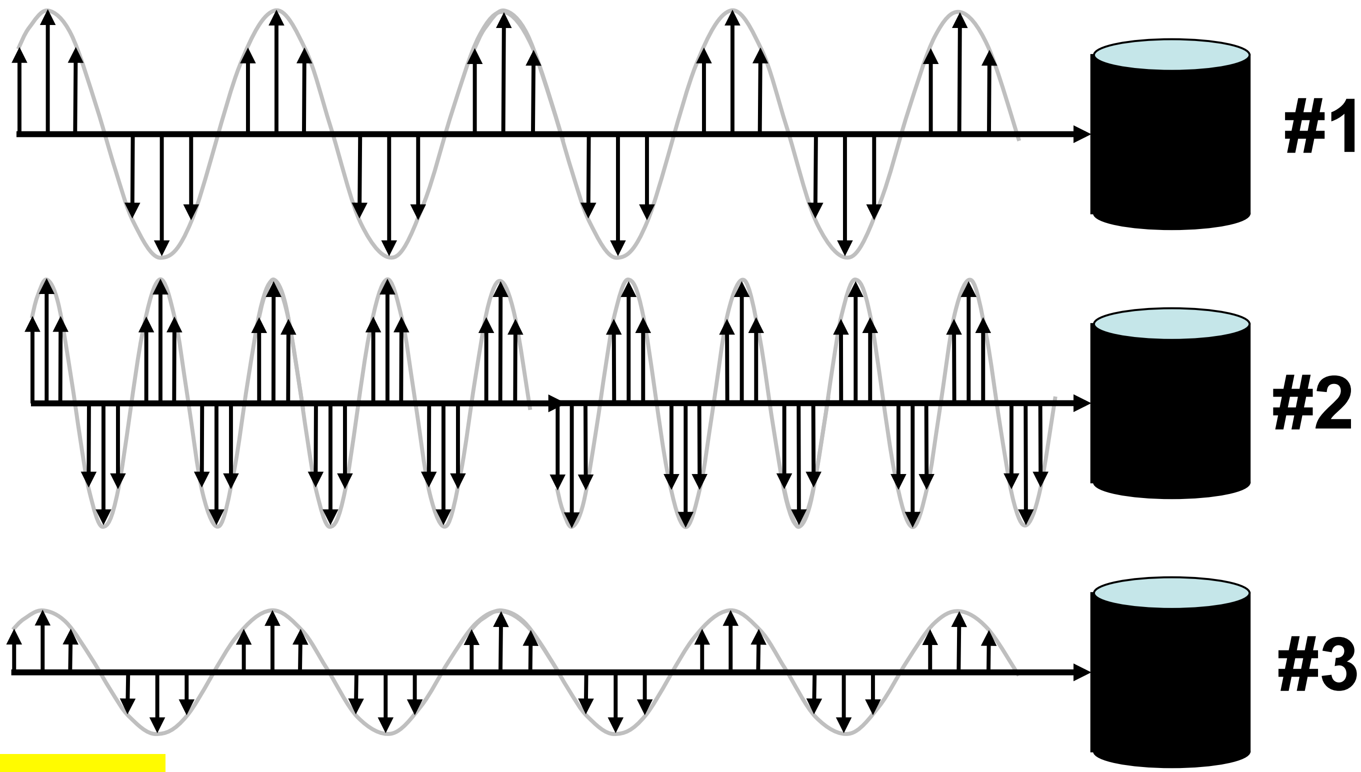
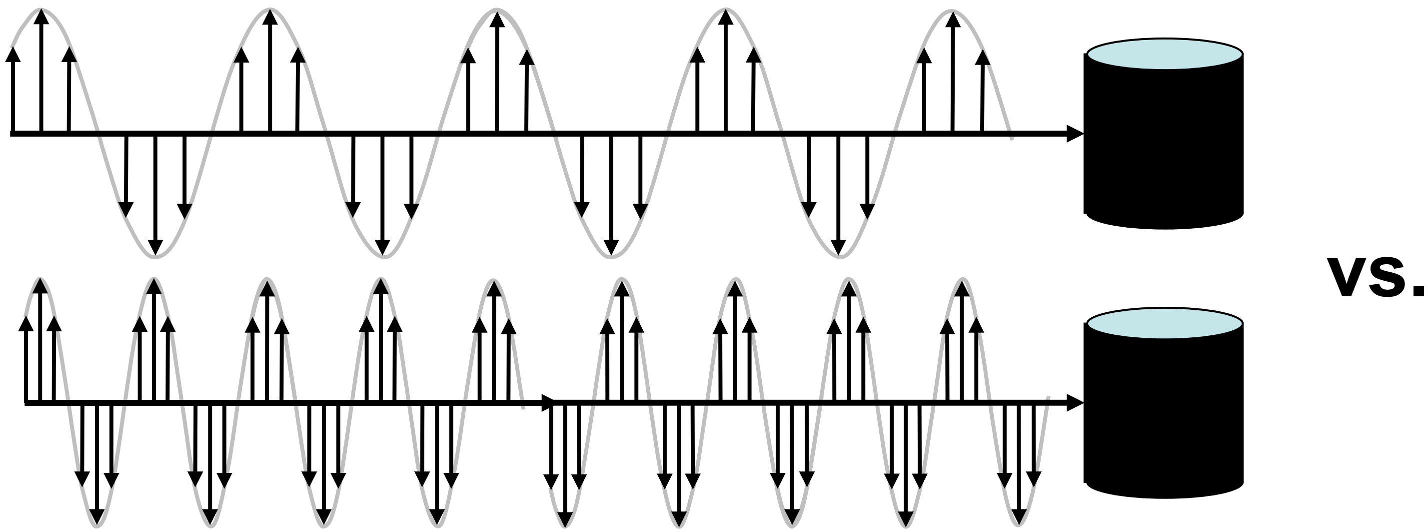


$E_{1max}=E_{2max}>E_{3max}$

$$\text{Intensity} = \frac{\text{Power}}{\text{area}} = \frac{\text{energy/time}}{\text{area}} \propto E_{avg}^2 \propto E_{max}^2$$

Recap: Intensity ∝ E_{max}^2 … what about frequency?



Interference was definitive test that light is a wave.

Questions you may have:

Why do higher frequency gamma rays carry more energy than lower frequency radio waves when frequency has nothing to do with intensity?
I was told that energy of light depends on frequency?

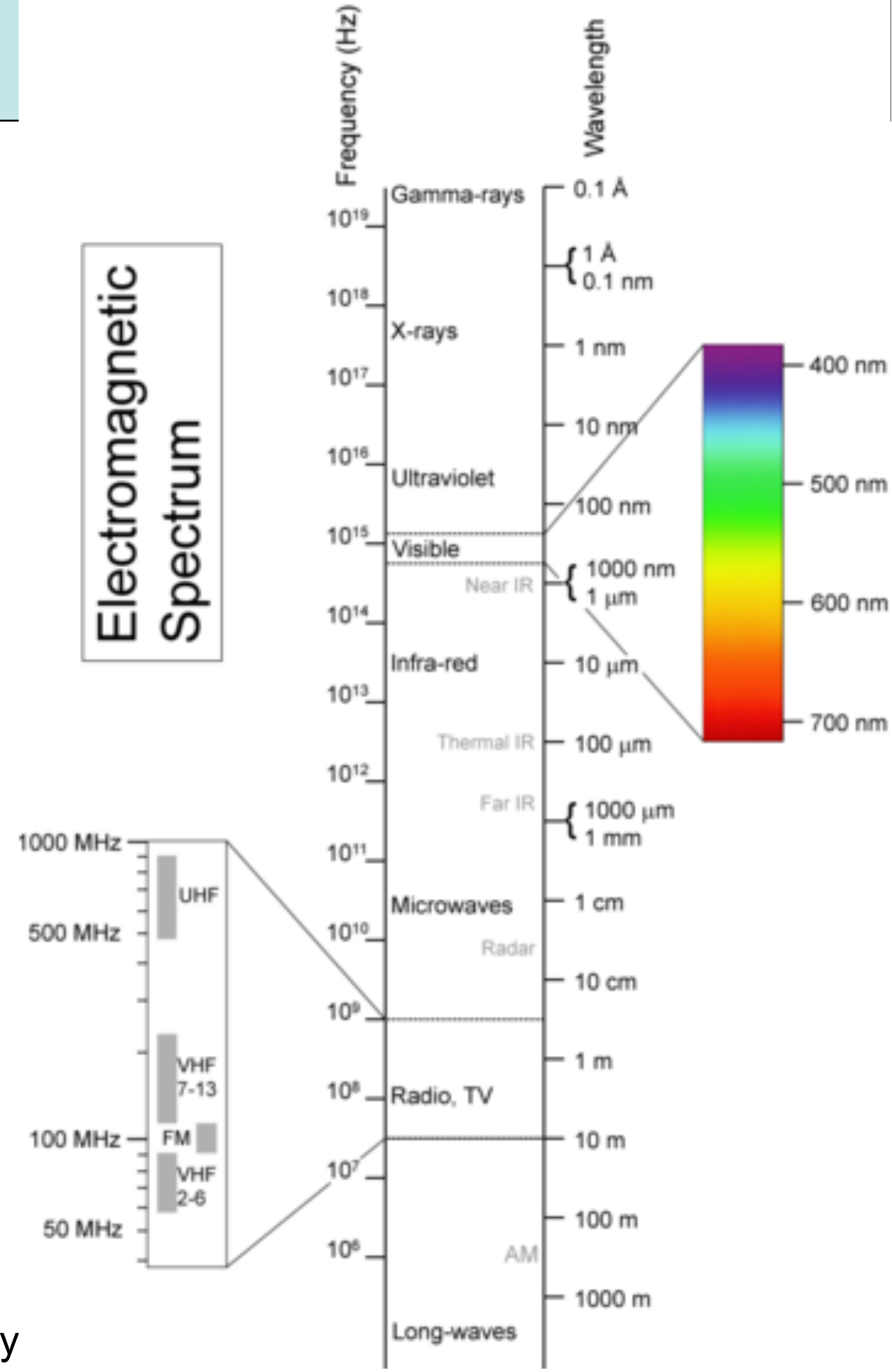
Confusion is between energy carried by a beam of light vs. energy in a single quantum particle of light

Features of light as a wave

Light has well defined frequency and wavelength extending from low frequency radio waves to microwaves to infrared to visible light to ultraviolet to X-rays to gamma rays.

Light exhibits interference and diffraction proving it is a wave.

The intensity of the light measures the power and is proportional to the square of the amplitude (with no dependence on frequency).



Blackbody radiation

A perfect blackbody absorbs all incoming radiation and emits radiation just due to the thermal energy.

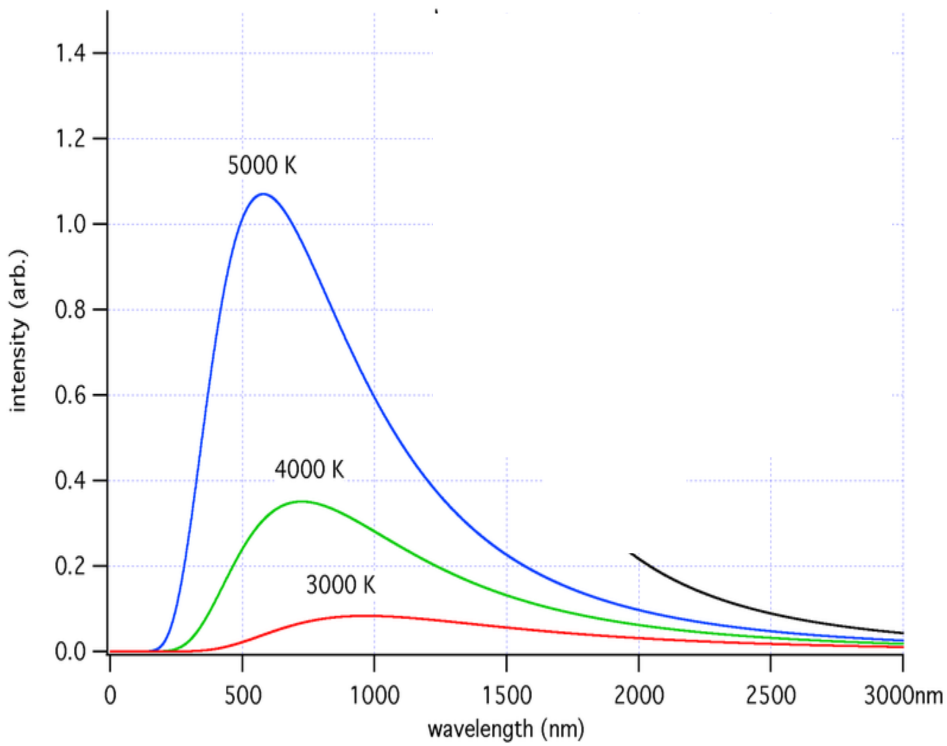
When a perfect blackbody is cold it emits almost zero radiation but absorbs everything to it appears black.

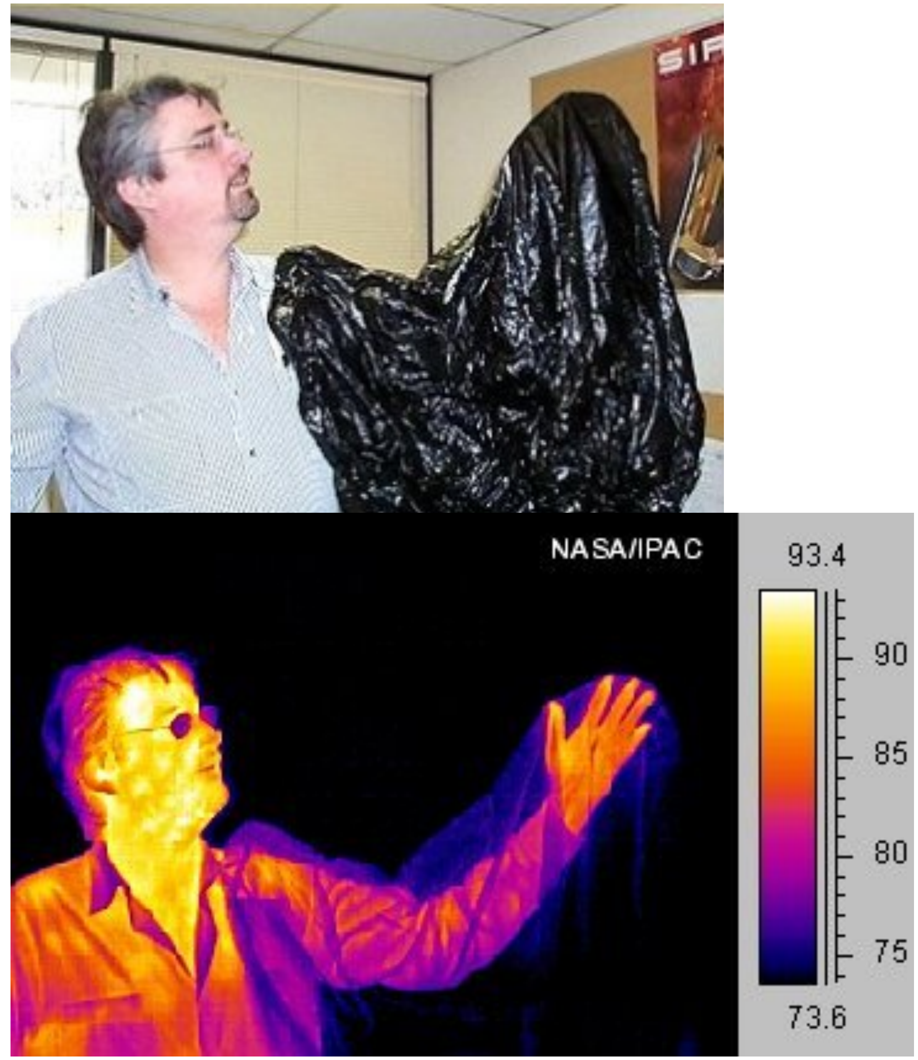
When hot, a blackbody emits a particular continuous spectrum of light which depends only on the temperature (not on the properties of the material).

Can measure blackbody temperature by looking at spectrum (color)

Blackbody spectrum

For relatively cool objects, most blackbody radiation is in the infrared; observable by thermal imaging devices.

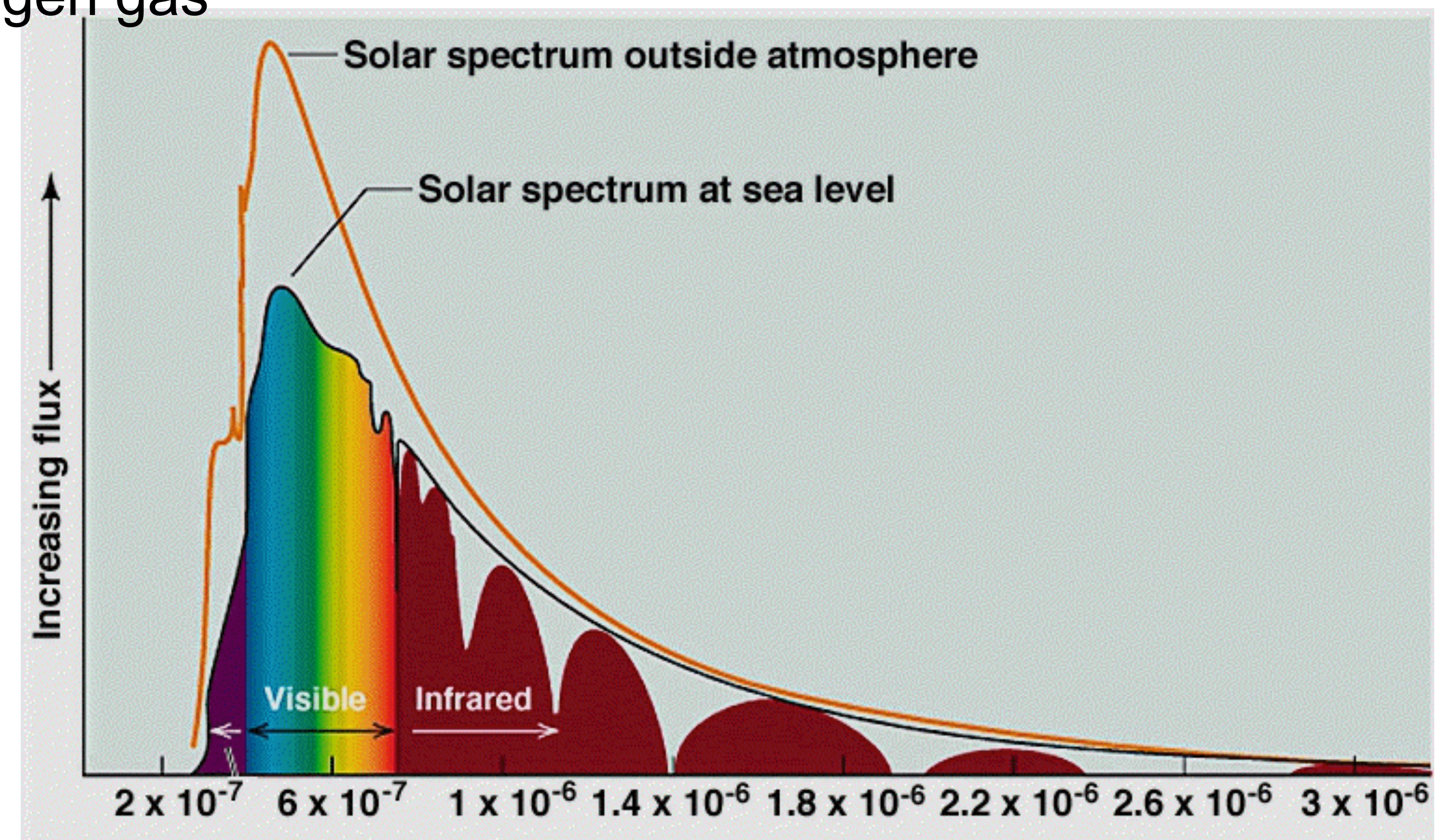




Sun is approximately a blackbody

The temperature of the surface of the sun is about 5800 K.

It is close to a black body although there are absorption lines from the hydrogen gas

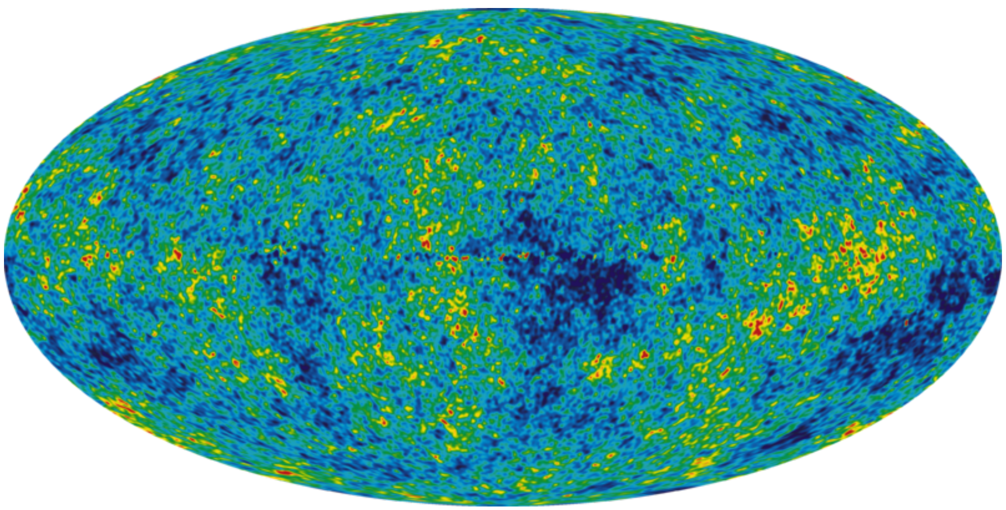


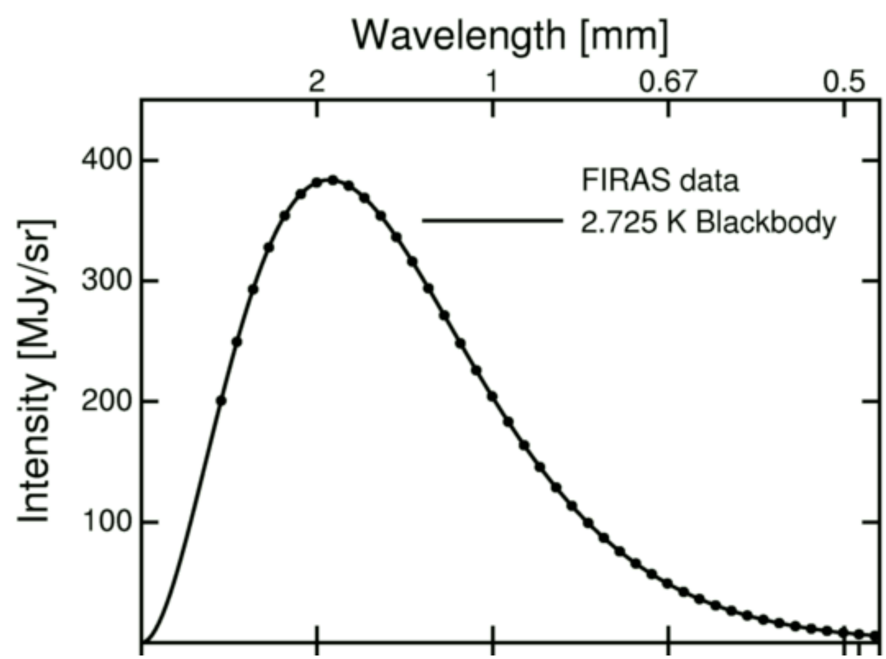
Cosmic Microwave Background (CMB)

The cosmic microwave background radiation comes from radiation that was emitted 13.3 billion years ago (400,000 years after the Big Bang).

At the time, the universe was about 3000 K but as the universe expanded, the wavelengths of the light increased so now it shows a blackbody at 2.725 K and is the most precise blackbody known.

Only 1 part in 100,000 anisotropy

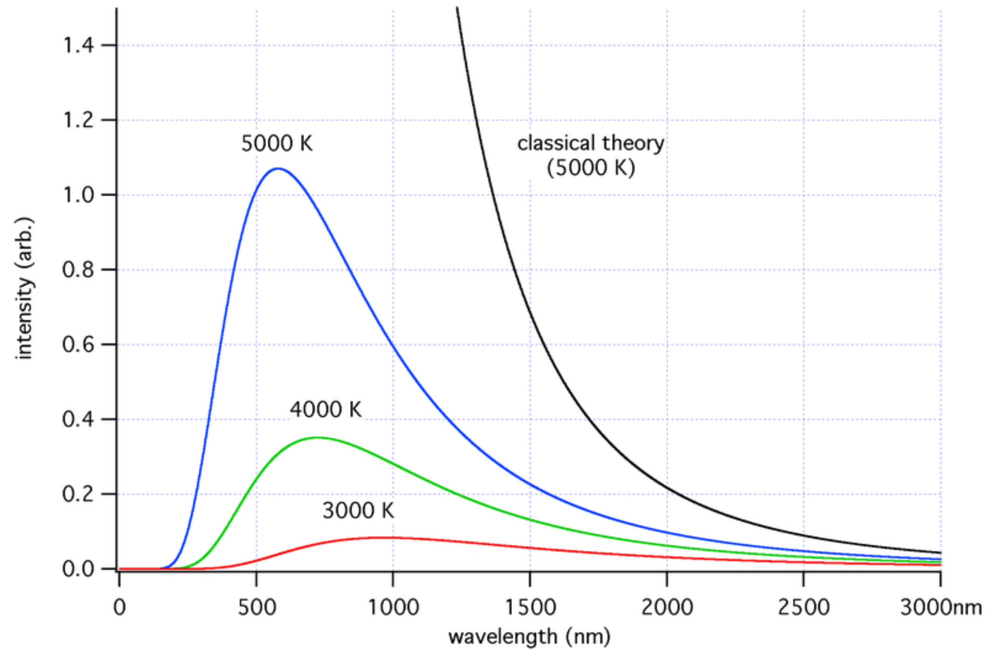




Clicker question 3	Set frequency to AD

Assuming stars are perfect blackbodies, what can you say about the relative surface temperatures of a blue giant, red giant, and our sun?

A. $T_{\text{blue giant}} = T_{\text{red giant}} > T_{\text{Sun}}$
B. $T_{\text{blue giant}} > T_{\text{red giant}} > T_{\text{Sun}}$
C. $T_{\text{blue giant}} > T_{\text{Sun}} > T_{\text{red giant}}$
D. $T_{\text{red giant}} > T_{\text{Sun}} > T_{\text{blue giant}}$
E. Depends on other factors



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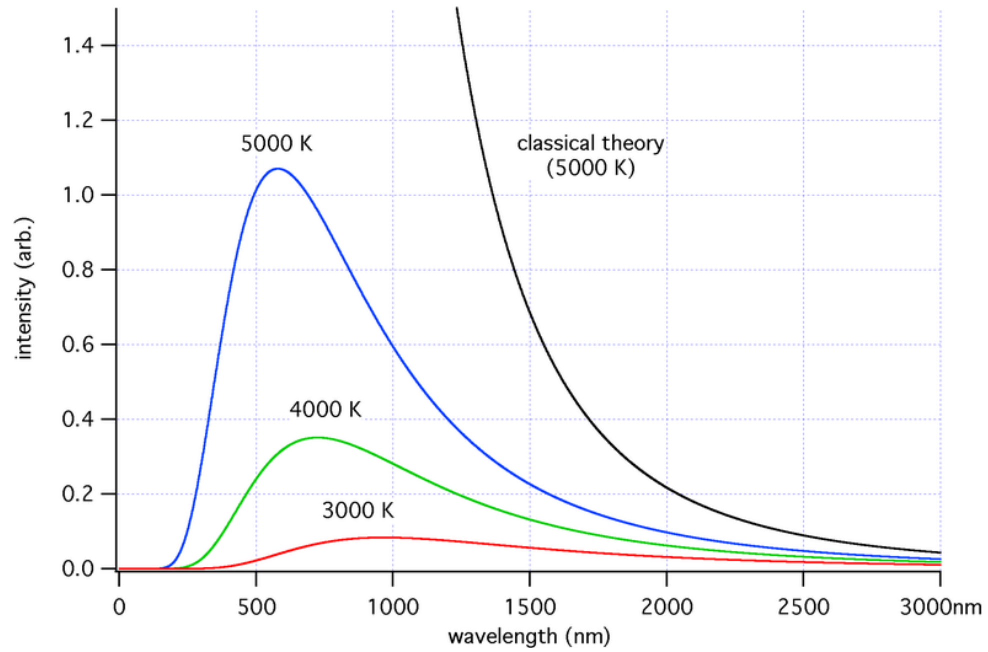

Our Sun is yellow!

Shorter wavelengths correspond to hotter blackbodies.