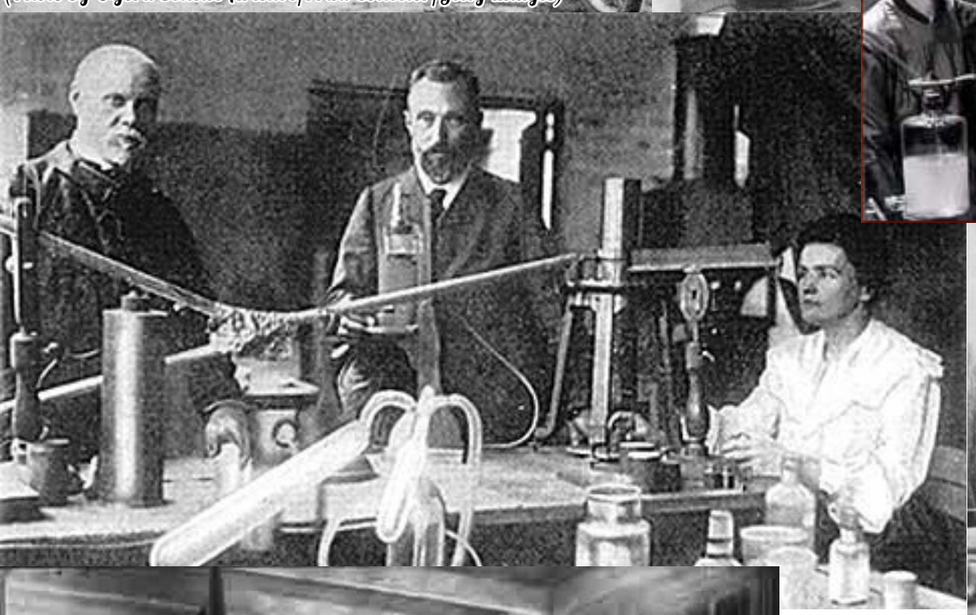
(Photo by Oxford Science Archive/Print Collector/Getty Images)



hi

Lecture 22, 30.03.2017

Quantum Mechanics 2

housekeeping

Question about anything?

I'll make a movie for you:

~~Marie Curie movie anyone?~~

~~*March 29: 6:30pm, BPS 1400*~~

~~*penultimate pizza poll pace peaked & pegged*~~

FakeFacebook is due April Fools Day. tee hee

Blog read-reflect project has started. it stinks

Next week's homework: back to MasteringPhysics

Manuscript chapters:

man_waves_up and man_quantum1_up in

`http://www.pa.msu.edu/~brock/file_sharing/QSandBB/QS&BB_manuscript/`

Honors Project

has begun. First milestone was last Friday.

Read the Second of two sets of instructions:

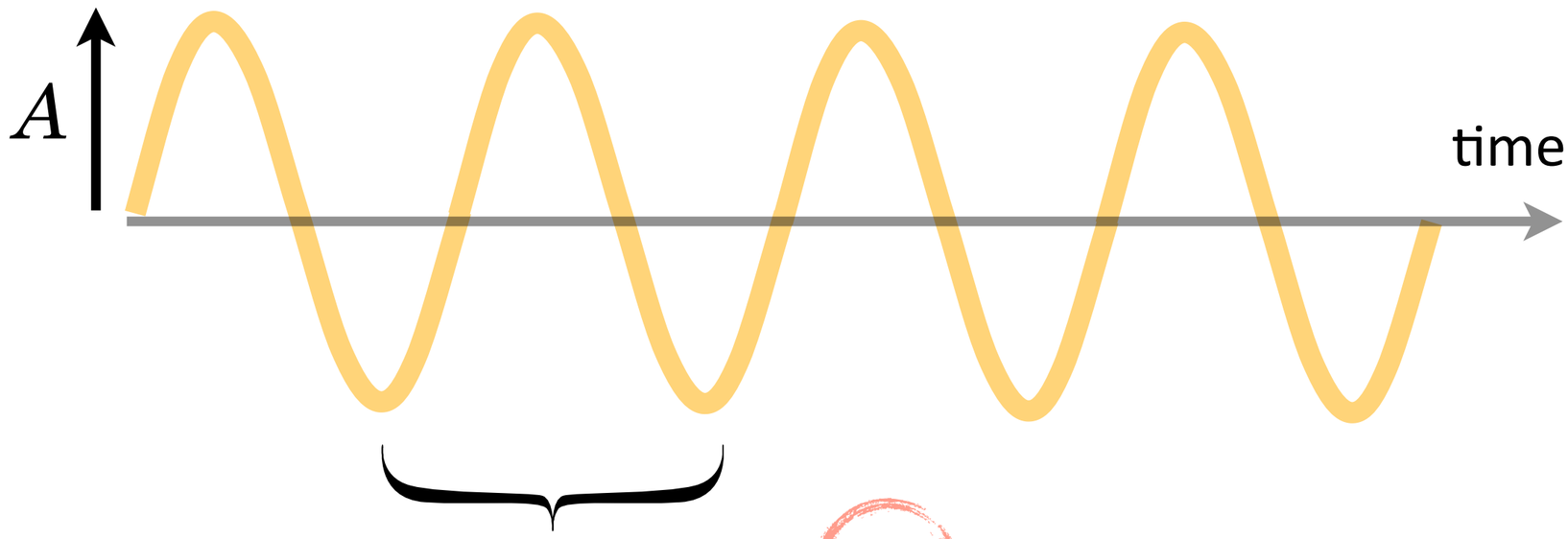
`MinervaInstructions2_2017.pdf` in

www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/honors_project_2017/

just some facts, Ma'am

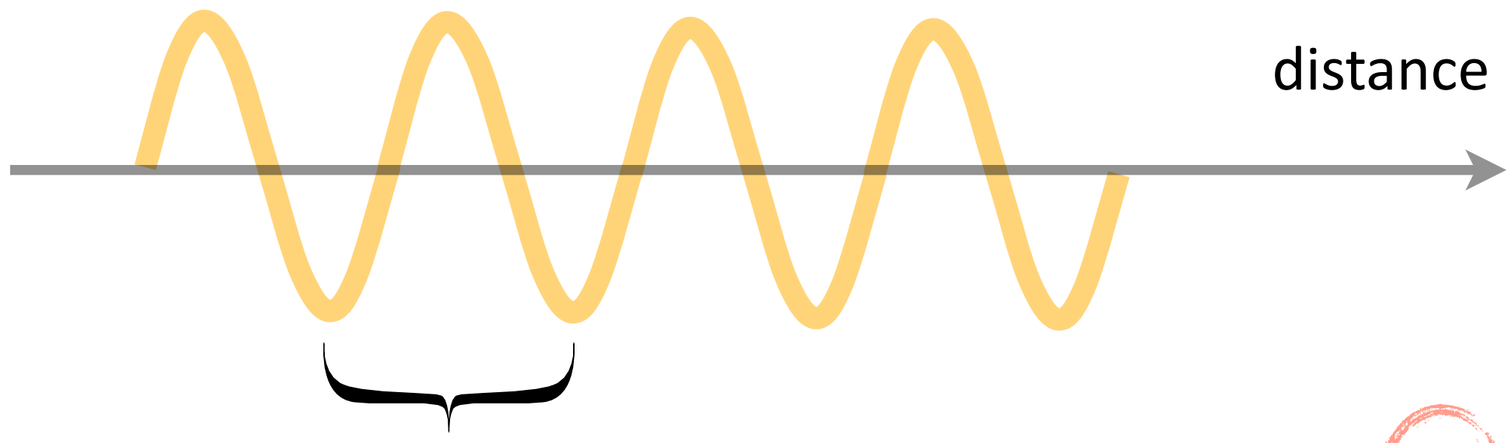
maximum height of the disturbance: "Amplitude," A.

"Intensity" is ~ A^2



time to repeat: "Period," T. seconds

rate of repetition: "Frequency," f. (Hz) $f = \frac{1}{T}$



distance through which it repeats: "Wavelength," λ m

$v = \frac{\lambda}{T}$ $v = \lambda f$

relation alert: **speed of a wave**

refers to: $v = \lambda f$

example: middle C ~ 4 ft (=1.2 m) wavelength

f = 262 Hz, so speed of sound:

$$v = 1.2 \times 262 = 314 \text{ m/s}$$

relation alert: **speed of an electromagentic wave**

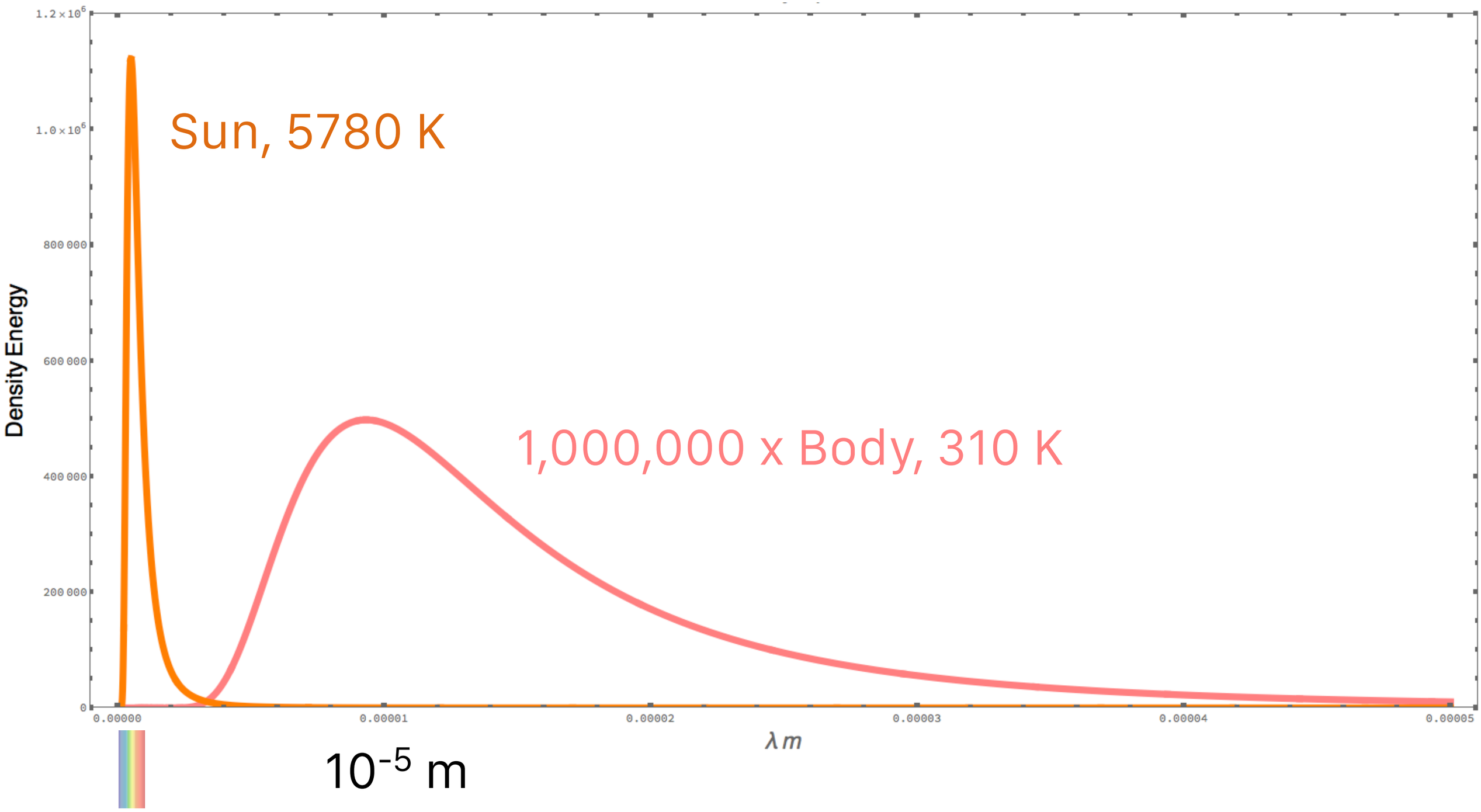
refers to: $$c = \lambda f$$

example:

body temperature corresponds to roughly λ = 10 x 10^{-6} m

f = 3 x 10^{13} Hz, since the speed of light is : $c = 3 \times 10^8 \ \mathrm{m/s}$

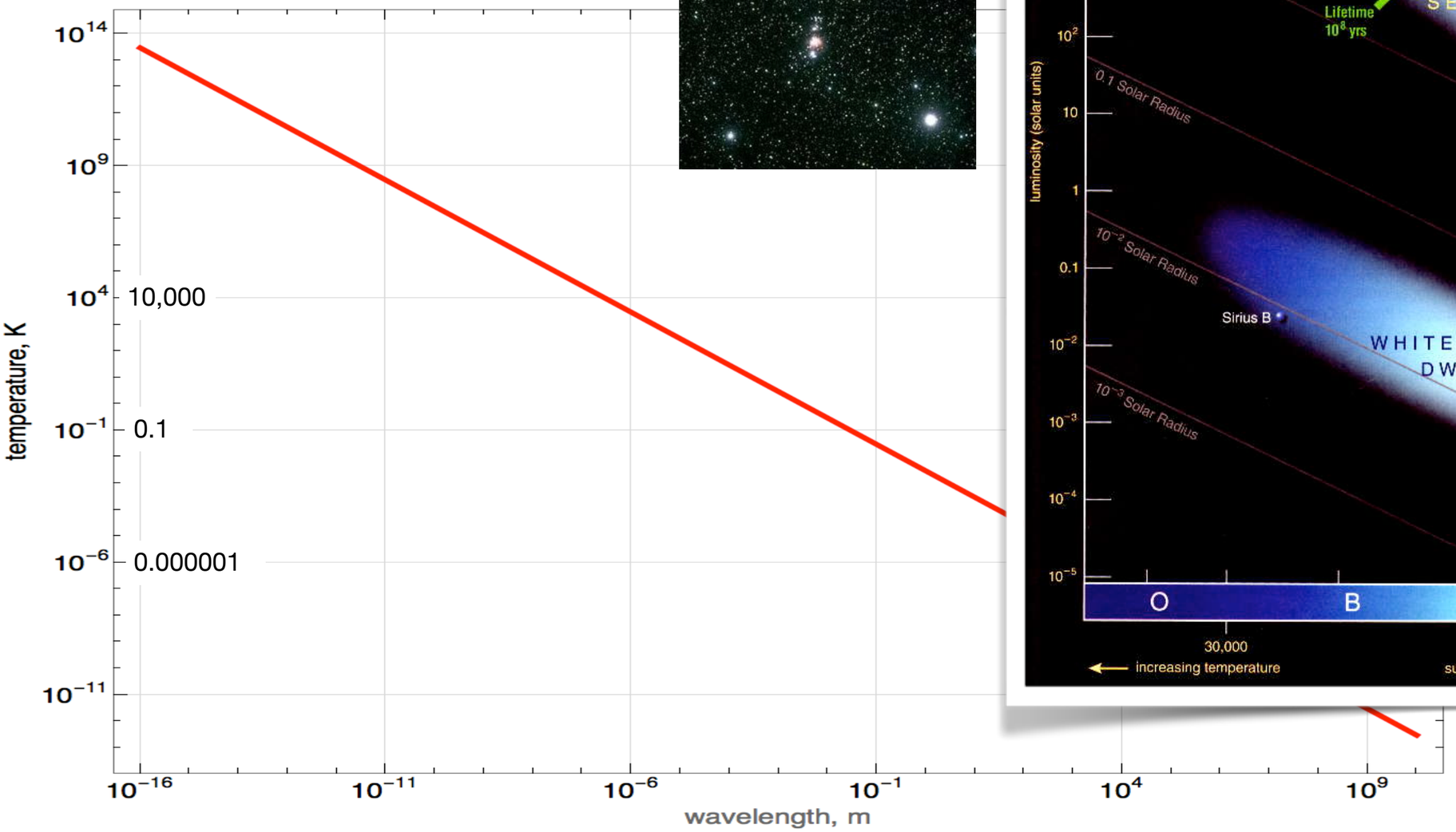
Sun’s warmth? notsomuch

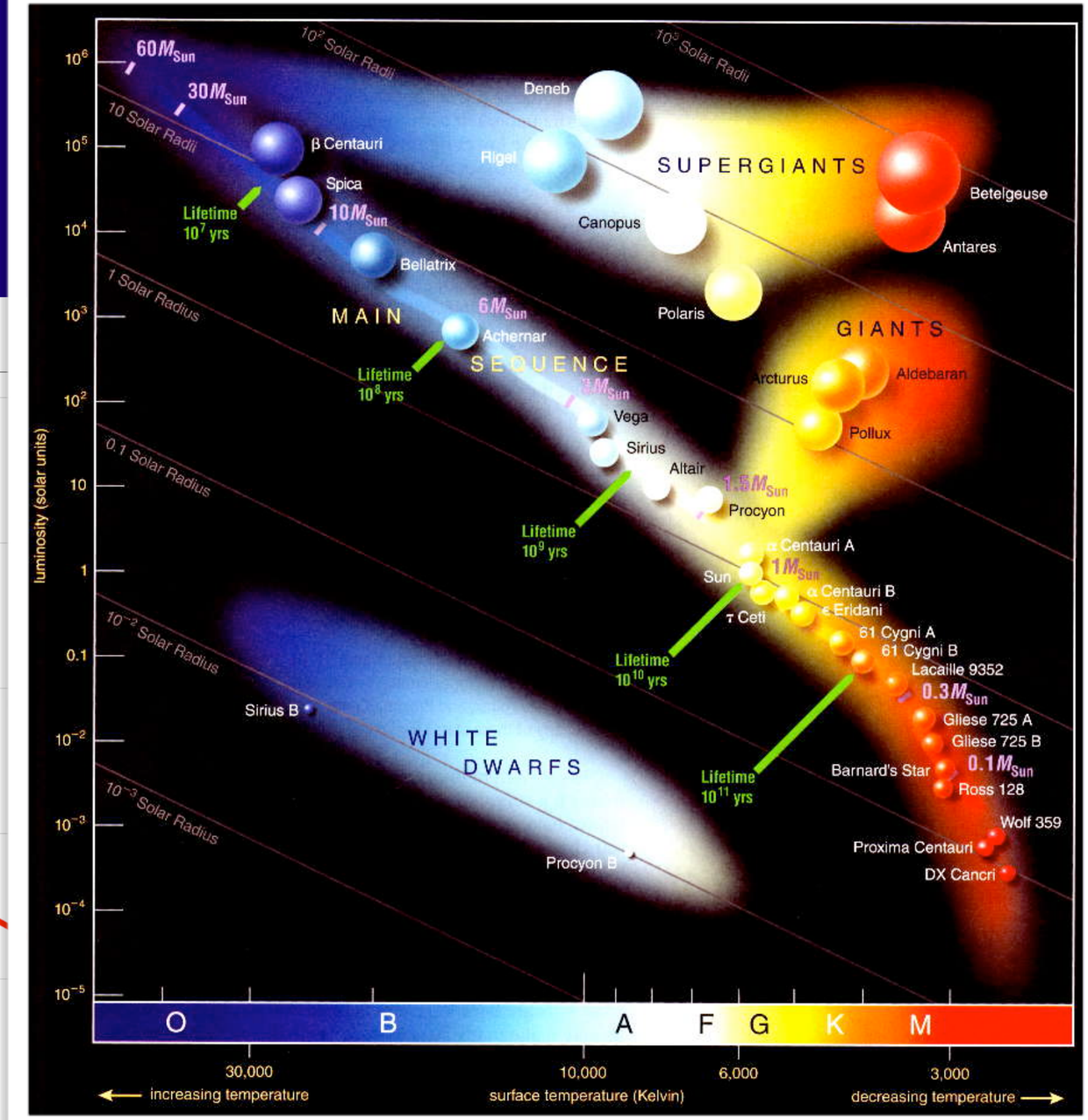


10^{-5} m

peak:


BELLATRIX
22,000K


temperature, K
10^{14}
10^{9}
10^{4}
10,000
10^{-1}
0.1
10^{-6}
0.000001
10^{-11}
10^{-16}
10^{-11}
10^{-6}
10^{-1}
10^{4}
10^{9}
wavelength, m


luminosity (solar units)
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{2} Solar Radii
10^{3} Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
$60M_{Sun}$
$30M_{Sun}$
$10M_{Sun}$
$6M_{Sun}$
$3M_{Sun}$
$1.5M_{Sun}$
$1M_{Sun}$
$0.3M_{Sun}$
$0.1M_{Sun}$
Lifetime 10^{7} yrs
Lifetime 10^{8} yrs
Lifetime 10^{9} yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
Deneb
Rigel
SUPERGIANTS
Betelgeuse
Antares
Canopus
β Centauri
Spica
Bellatrix
Polaris
MAIN
SEQUENCE
Achernar
GIANTS
Aldebaran
Pollux
Vega
Sirius
Altair
Procyon
α Centauri A
Sun
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
WHITE
DWARFS
Procyon B
O
B
A
F
G
K
M
30,000
increasing temperature
10,000
surface temperature (Kelvin)
6,000
3,000
decreasing temperature

γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^{-16}
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
λ (m)
Increasing Wavelength (λ) →

relation alert: **Planck's Law**

refers to: $E = hf$

Energy of radiation comes in a discrete amount for each frequency

example: photoelectric effect

constant of nature:

Planck's Constant, h

value: $h = 6.62606896(33)\times10^{-34}$ J-sec

units: Energy - time

usage: everything at atomic and smaller sizes

Einstein said:

in that famous 1905 year

Planck's bundles are not about the walls...the radiators

It is a statement about light (electromagnetism)

Light is itself "quantized"

....as particles:

these particles are called:

"photons," γ

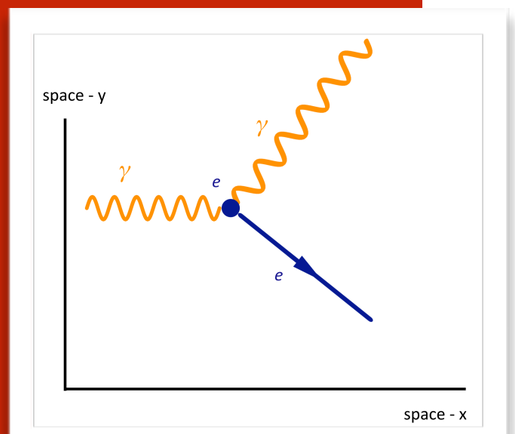
they have no mass

particle:	**photon, γ**
symbol:	γ
charge:	0
mass:	0
spin:	1
category:	an intermediate vector boson, a messenger particle

Compton scattering

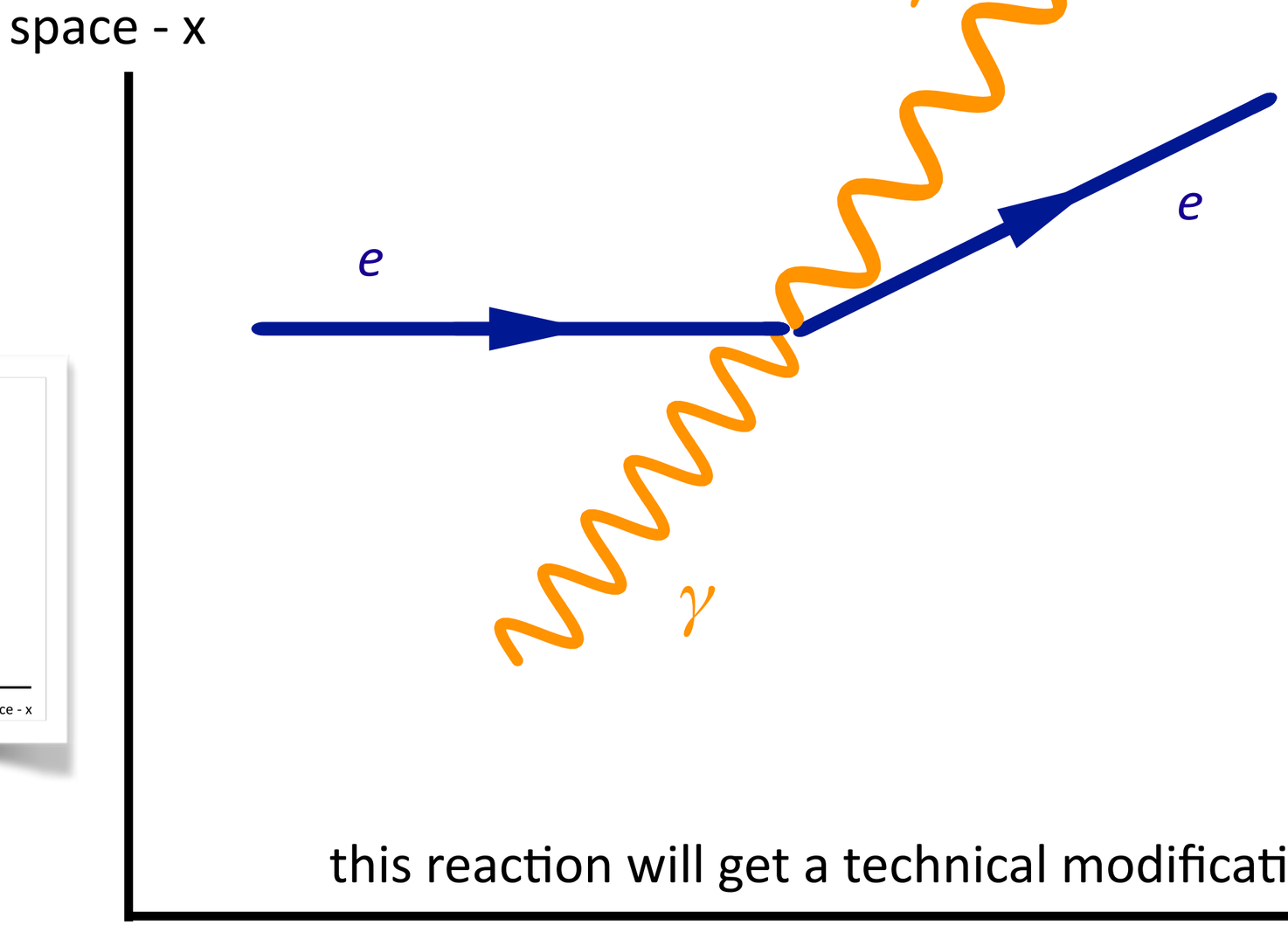
spacetime diagram

aka, *Feynman* diagram



draw the Feynman diagram for Compton Scattering

$$\gamma + e \rightarrow \gamma' + e'$$



here's the connection

between the wave nature and the particle nature

of light

the wave point of view:

$$\text{Intensity} \propto |\vec{E}|^2$$

the particle point of view:

$$\text{Intensity} \propto Nhf$$

$$N \propto |\vec{E}|^2$$

intensity, or power

number of photons

~10^{15} γ/s

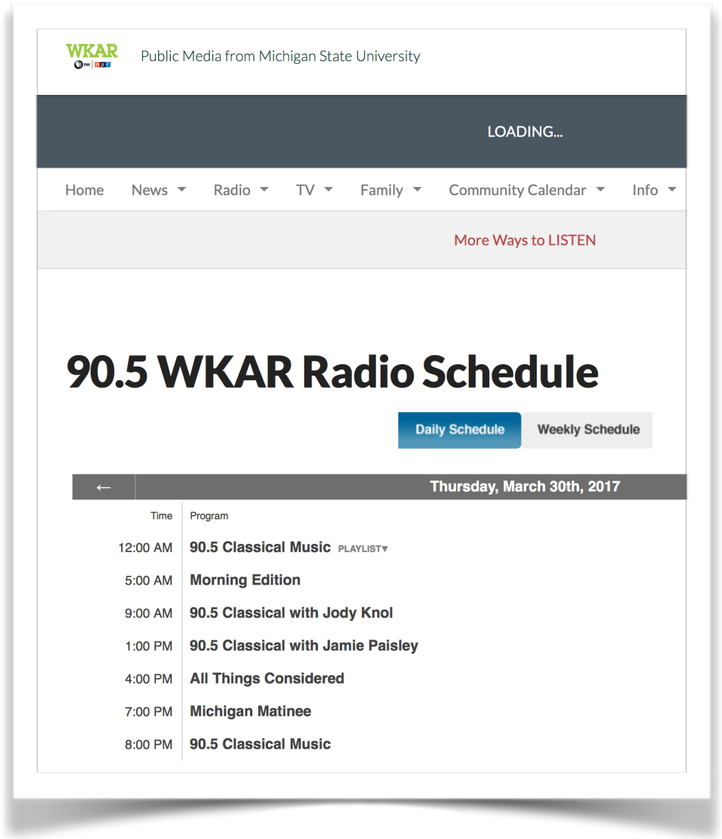
1m

radio

wavelengths

what are the wavelengths?

what are the photon energies?



WKAR Public Media from Michigan State University

LOADING...

Home | News | Radio | TV | Family | Community Calendar | Info

More Ways to LISTEN

90.5 WKAR Radio Schedule

Daily Schedule | Weekly Schedule

← Thursday, March 30th, 2017

Time	Program
12:00 AM	90.5 Classical Music PLAYLIST
5:00 AM	Morning Edition
9:00 AM	90.5 Classical with Jody Knol
1:00 PM	90.5 Classical with Jamie Paisley
4:00 PM	All Things Considered
7:00 PM	Michigan Matinee
8:00 PM	90.5 Classical Music

$f = 90.5$ MHz

FM: 88 - 108 MHz

AM 870 NewsTalk Radio Schedule

Daily Schedule | Weekly Schedule

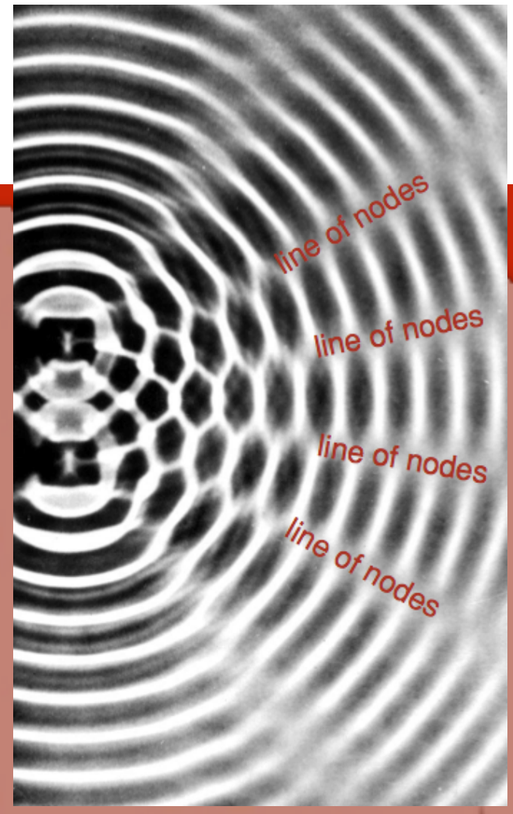
← Thursday, March 30th, 2017

Time	Program
12:00 AM	Newsday
12:30 AM	The Food Chain
1:00 AM	Newsday
2:00 AM	The Thought Show
3:00 AM	Newsday
3:30 AM	Healthcheck
4:00 AM	The Compass
4:30 AM	Business Daily
4:50 AM	Witness
5:00 AM	World Update
6:00 AM	The Newsroom
6:30 AM	Assignment
7:00 AM	Outlook
8:00 AM	The Newsroom
8:30 AM	Business Daily / Witness

$f = 870$ kHz

AM: 535 - 1605 kHz

keep those in mind



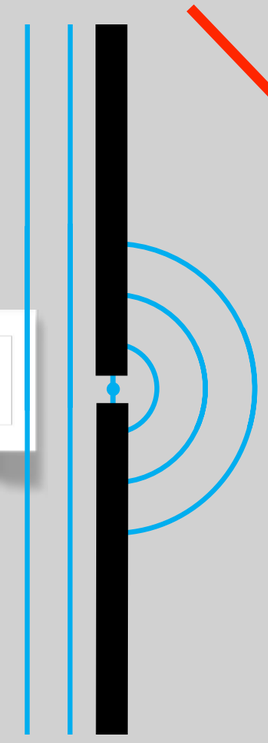
1 and 2 taps

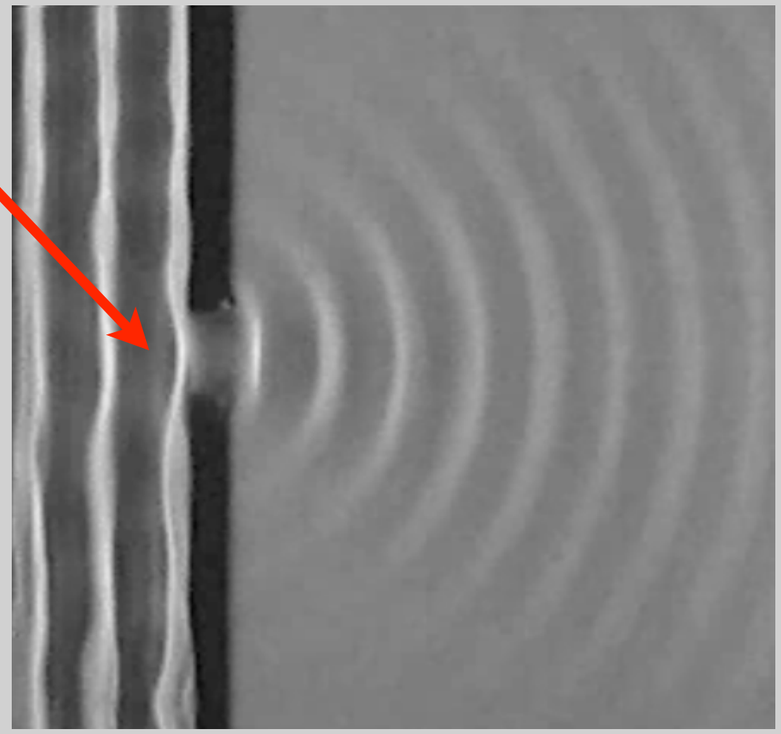
a plane wave impinging on a gap

like 1 "tap"

a gap of about a wavelength-width

plane waves





like the 1-tap image

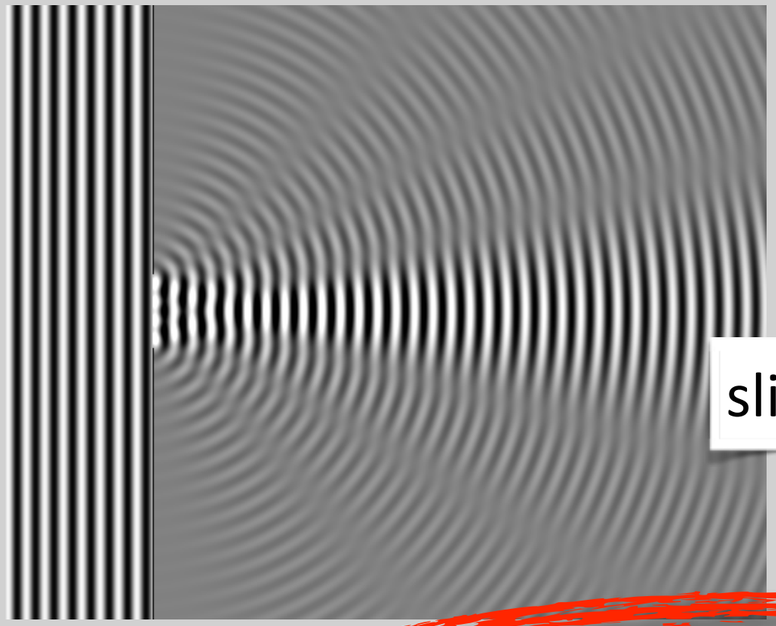
Another smoking gun of wave-behavior
(as opposed to particle behavior)

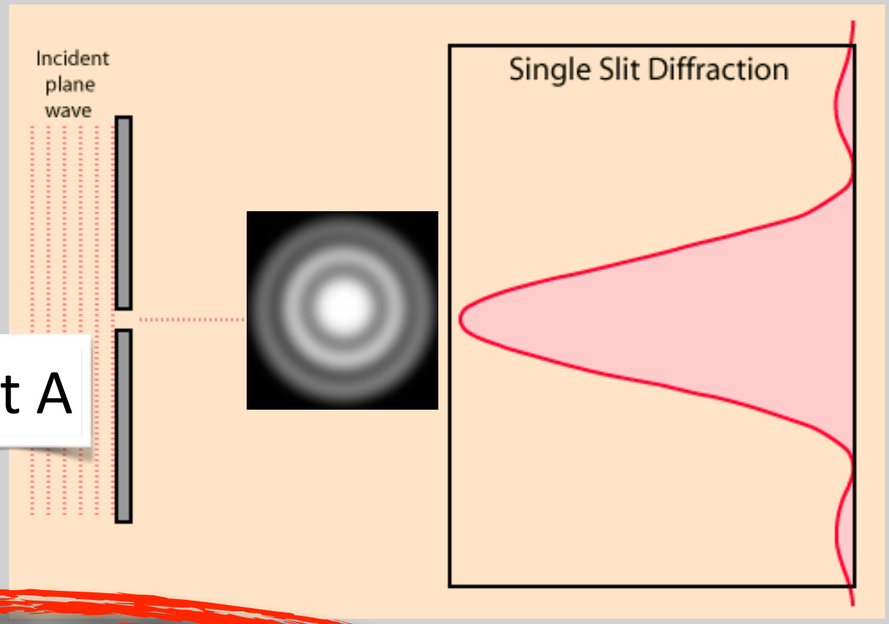
This is diffraction

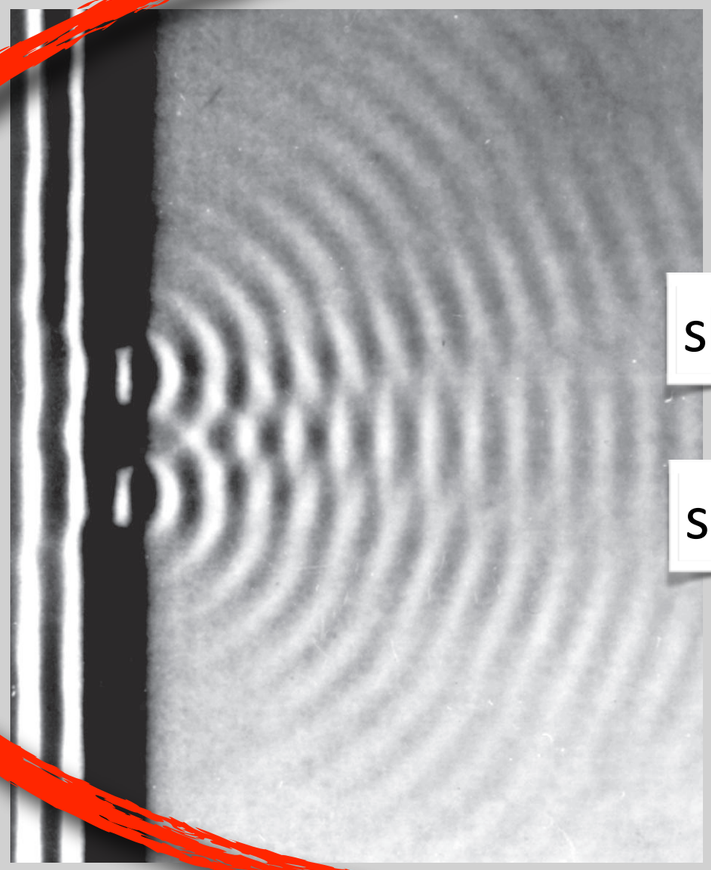
...the bending of the wave around the opening.

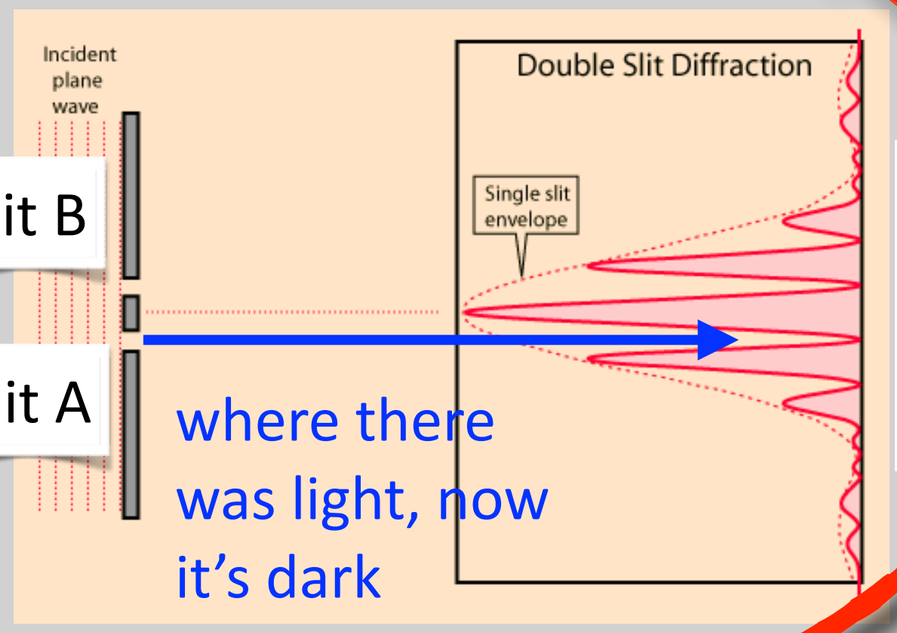
interference of light

and diffraction at the same time





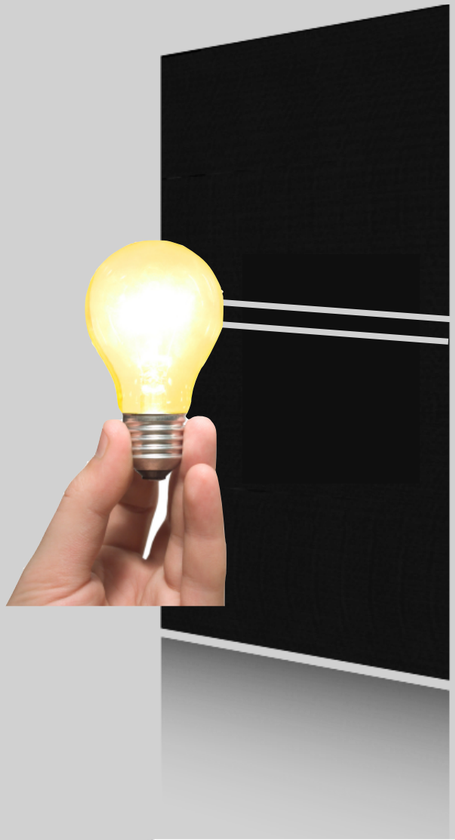




here's how it works

let light go through a double slit

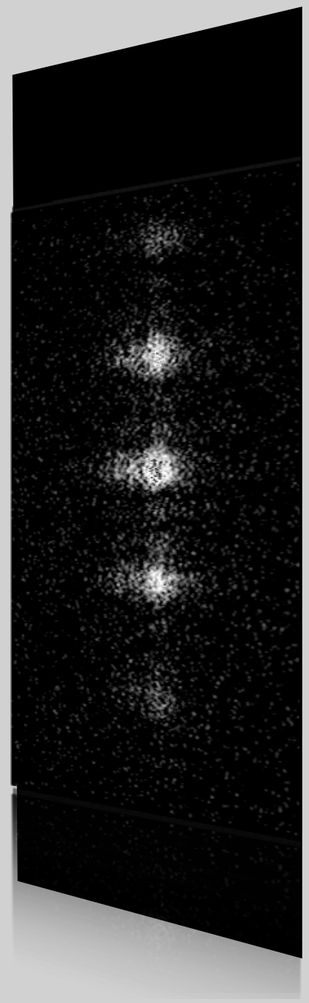
but sensitively count individual photons

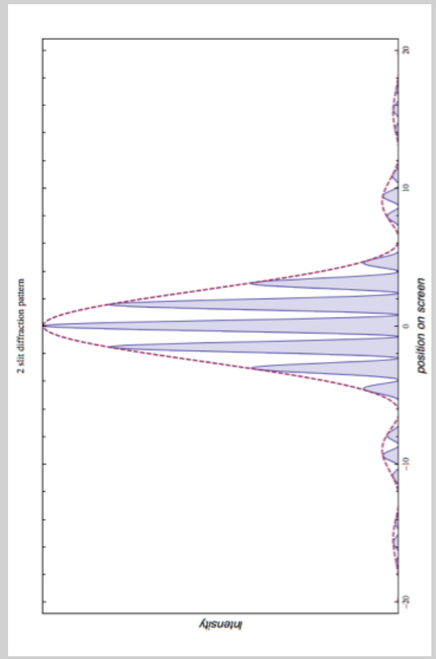


individual light particles

actual photons

γ





http://www.youtube.com/watch?v=MbLzh1Y9POQ

David Dykstra, Steven Busch, Wouter Peeters, Martin vanExter, Leiden University, 2008

So, here we go. Quantum strangeness in action.

light behaves like a wave

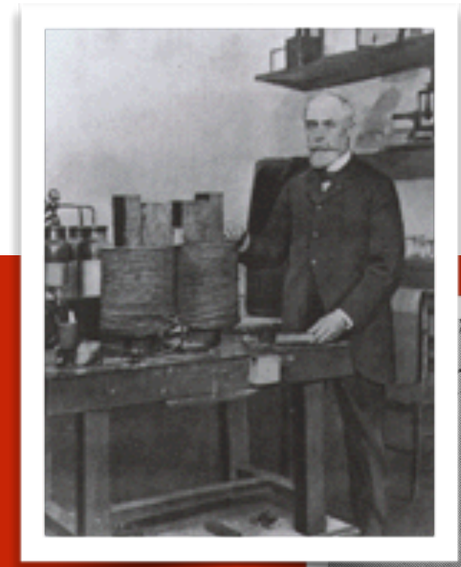
and light behaves like a particle

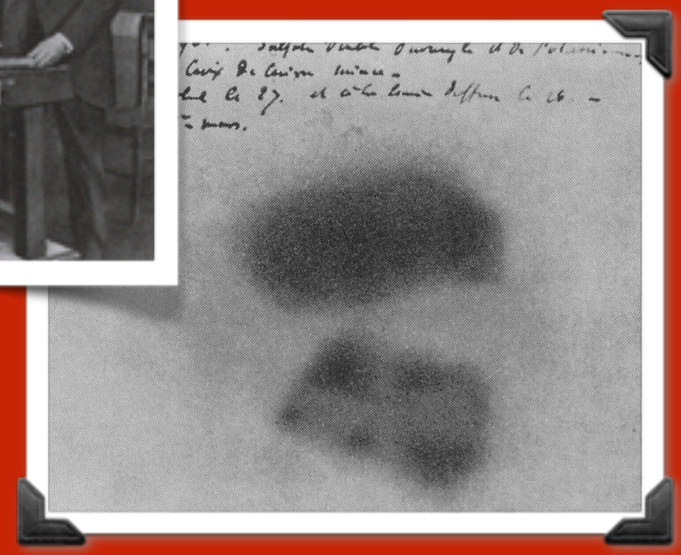
rewind a bit

to the beginning of Nuclear Physics

remember when we last saw the beginnings of radioactivity

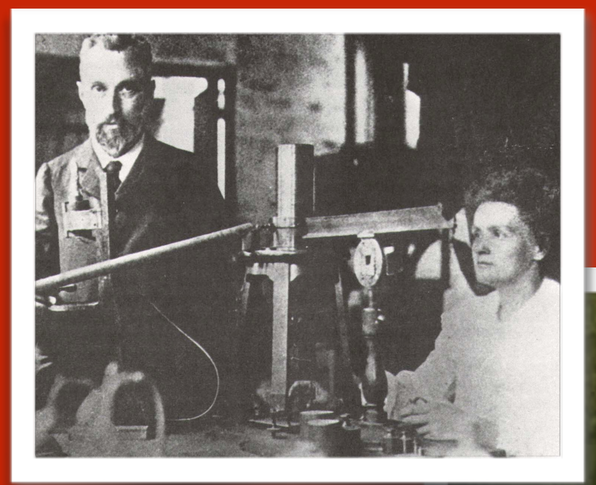
Becquerel’s adventures in cloudy Paris

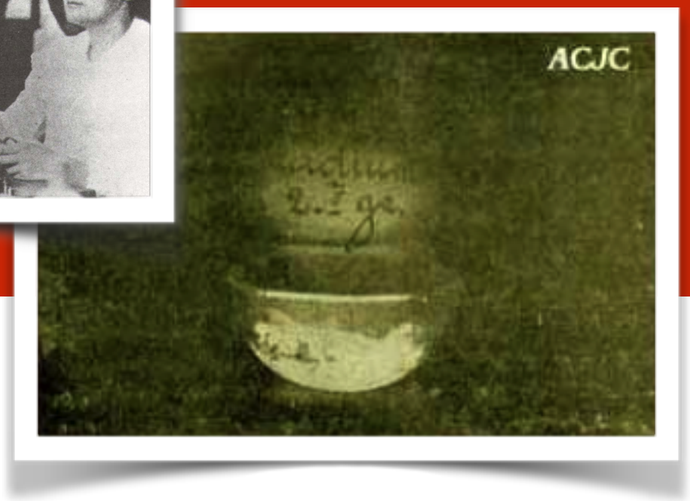


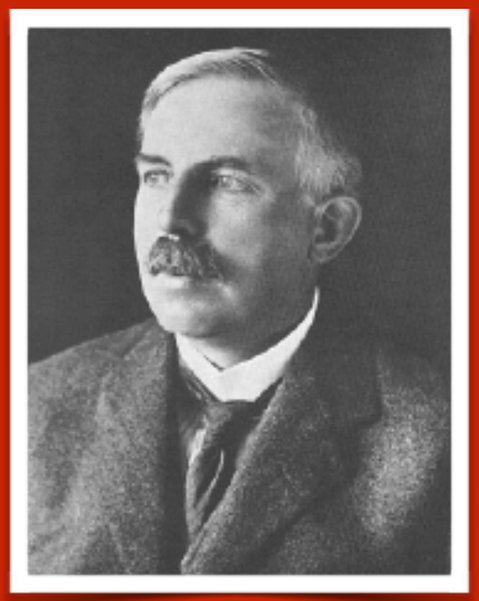


Marie and Pierre Curies’ isolation of Polonium and Radium

it was clear that matter could fall apart…”decay”







1899

Ernest Rutherford

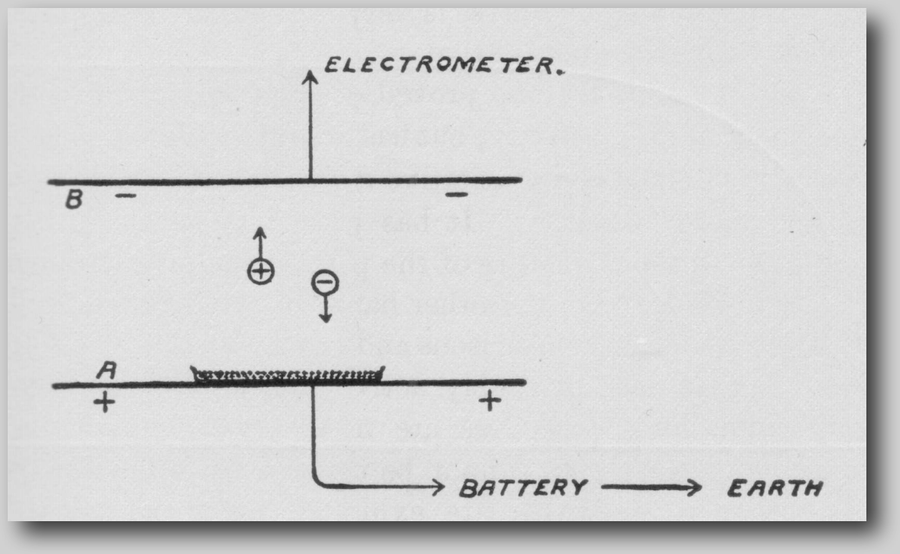
1871 – 1937

the nuclear physics’ 800 lb gorrilla

> I have to keep going, as there are always people on my track. The best sprinters in this road are Becquerel and the Curies.

The epitome of the aggressive scientist...

but I mean that in a good way.



He measured the actual current from radioactive decays.

1899: he carefully isolated 2 components of radiation:

one stopped by thin aluminum

one highly penetrating

and one more

and figured out another found in 1903:

γ neutral gamma rays

negatively charged, passes through matter relatively easily

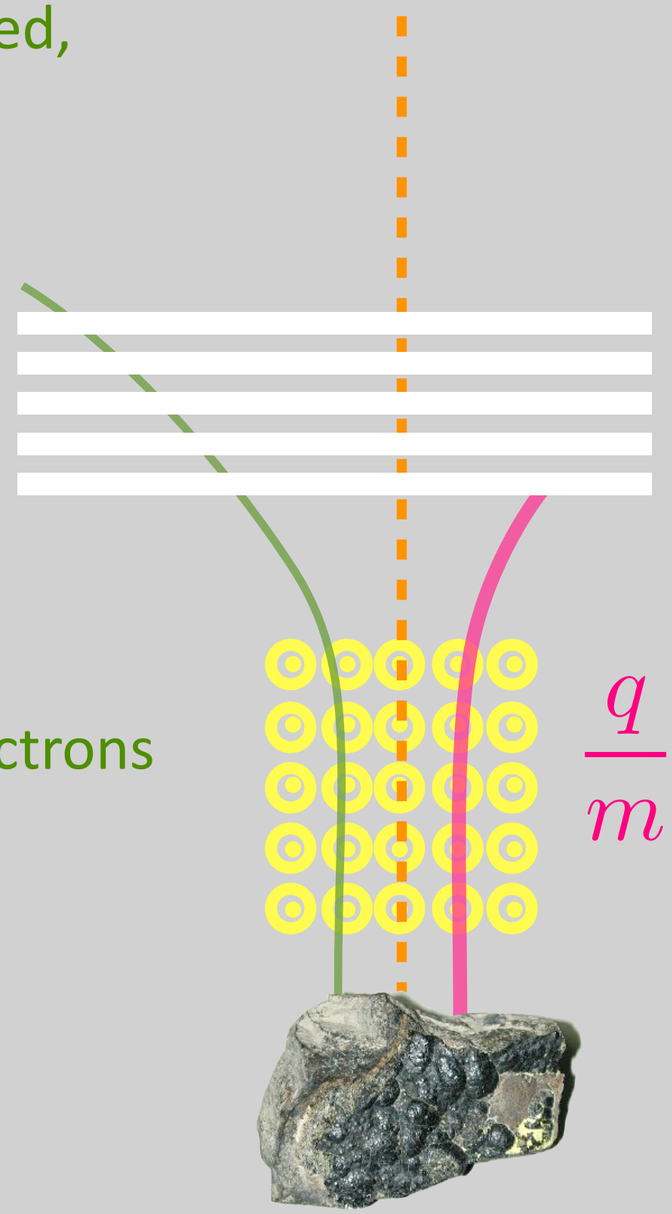
β

beta rays

positively charged, easily stopped in matter

α

alpha rays



$\frac{q}{m}$ → electrons

$\frac{q}{m}$ → 2 x H atom

↓

Helium nuclei

beta particles,

jargon alert: β (old name for an electron)

refers to: the emission of an electron in the decay of some nuclei - **<u>beta decay</u>**

entomology: alpha, beta,...

example: Carbon-14 → Nitrogen-14 + e

jargon alert:

alpha particles, α

(old name for a Helium nucleus)

refers to: the emission of a Helium nucleus in decay of some nuclei - **alpha decay**

entomology: alpha, beta,....

example: Uranium-238 → Thorium-234 + e

meanwhile

Rutherford had made his own career

McGill University in Montreal, 1900-1903

chemists still held to the (new) notion that atoms were indivisible

physicists were becoming convinced that atoms had structure and maybe made of constituents

Rutherford was convinced that matter was transmutating from one element to another...somehow

He entered into a heated debate with chemist Frederick Soddy....

> "Perhaps Professor Rutherford may be able to convince us that matter as known to him is really the same matter as known to us... I feel sure that chemists will retain a belief and reverence for atoms as concrete and permanent identities, if not immutable, certainly not yet transmuted"

Instead...they collaborated.

> "I am expected to do a lot of original work and to form a research school to knock the shine out of the Yankees."
>
> Rutherford
>
> to his fiancée upon his appointment at McGill University in Montreal, 1898

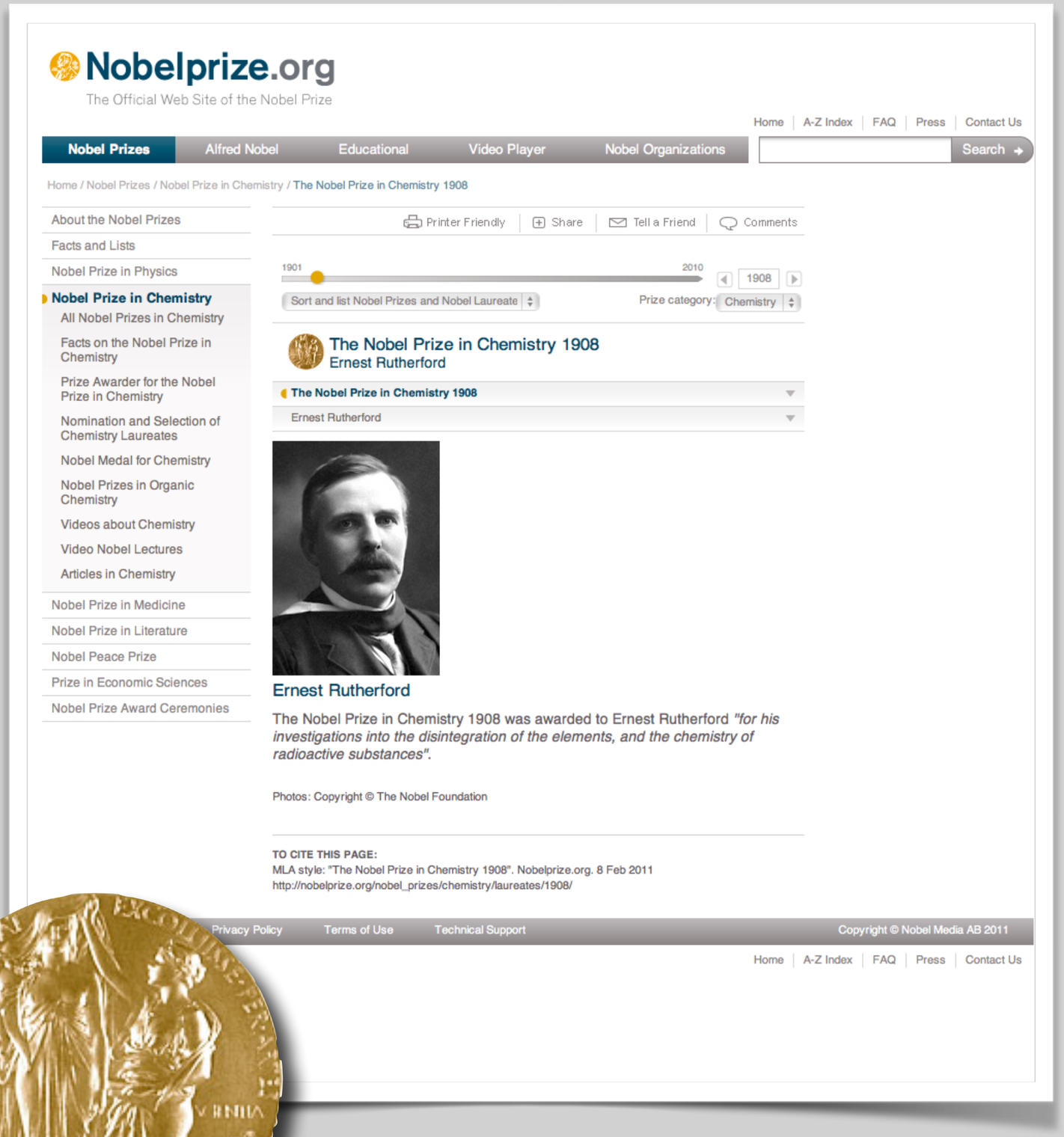
Nobel Prize in Chemistry

1908

which greatly amused him

and went on

to do his best work after his Nobel...very unusual



finally, 1918

Planck got his due

Nobelprize.org

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1901 — 2012 — 1918

Sort and list Nobel Prizes and Nobel Laur — Prize category: Physics

The Nobel Prize in Physics 1918
Max Planck

The Nobel Prize in Physics 1918

Max Planck

Max Karl Ernst
Ludwig Planck

The Nobel Prize in Physics 1918 was awarded to Max Planck *"in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta"*.

Max Planck received his Nobel Prize one year later, in 1919. During the selection process in 1918, the Nobel Committee for Physics decided that none of the year's nominations met the criteria as outlined in the will of Alfred Nobel. According to the Nobel Foundation's statutes, the Nobel Prize can in such a case be reserved until the following year, and this statute was then applied. Max Planck therefore received his Nobel Prize for 1918 one year later, in 1919.

Photos: Copyright © The Nobel Foundation

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http://www.nobelprize.org/nobel_prizes/physics/laureates/1918/

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Max Planck, 1916

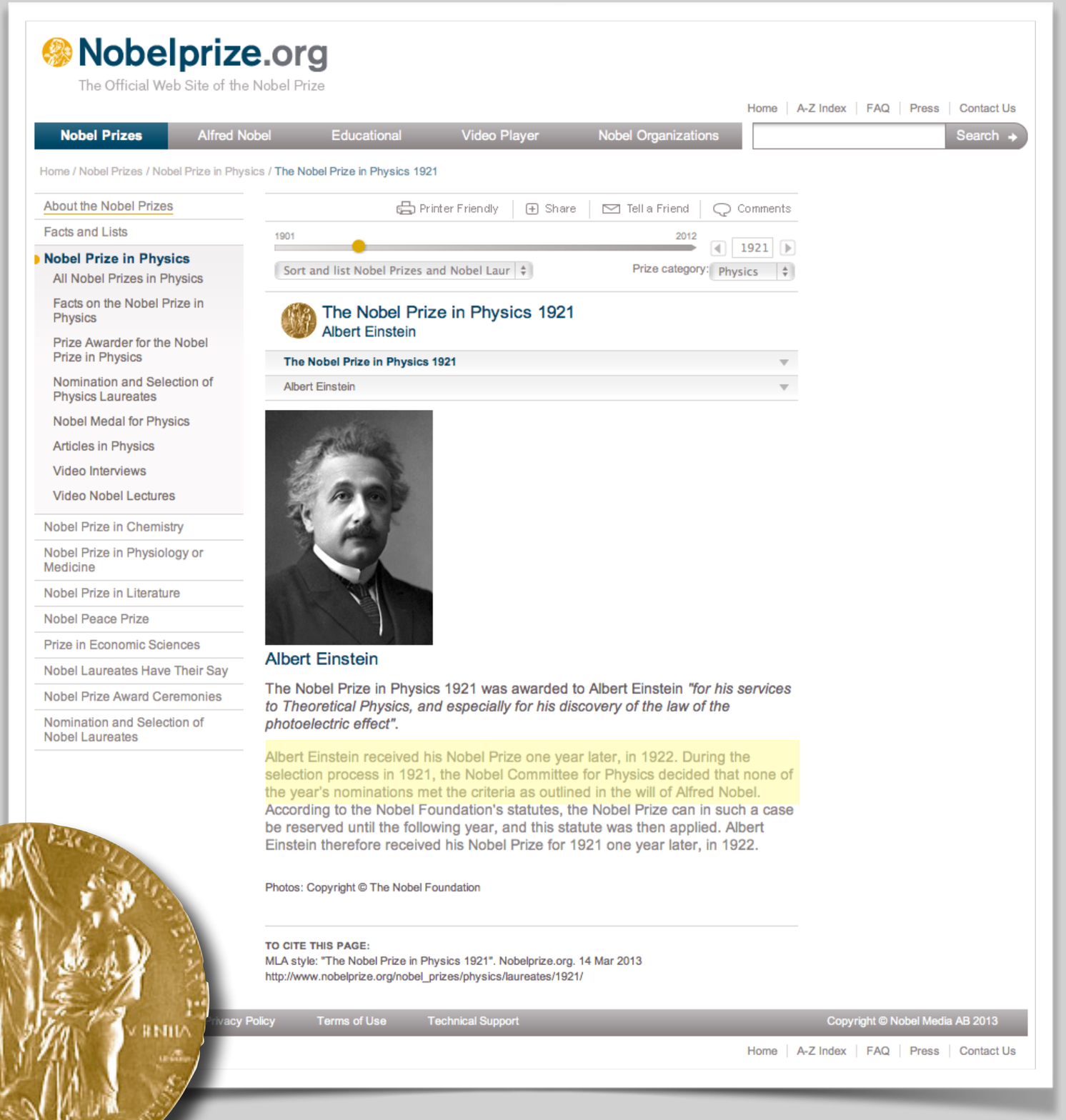
On nominating Einstein for membership in the Prussian Academy of Sciences:

“That he may sometimes have missed the mark in his speculations, as for example in his hypothesis of light quanta, cannot really be held too much against him. For it is not possible to introduce fundamentally new ideas, even in the most exact sciences, without occasionally taking a risk.”

finally

the 1921 prize, given in 1922

not the Nobel's finest hour.



so where are we, circa 1910 or so?

the electron appears to exist and so do atoms

matter is falling apart - spontaneously, and randomly

into 3 distinct kinds of “rays”

light appears to be wave-like and particle-like

so, what's in the atom

from a 1910 perspective?

Look what people were contending with:

electrons produced at the cathode of a cathode ray tube.

electrons seemed to spontaneously pop out of some nuclei.

yet, bulk matter is not electrically charged...so there is some positive charge somewhere

JJ had a model:

"Plum-pudding" model of atom

pudding: *a continuous + charge and mass distribution*

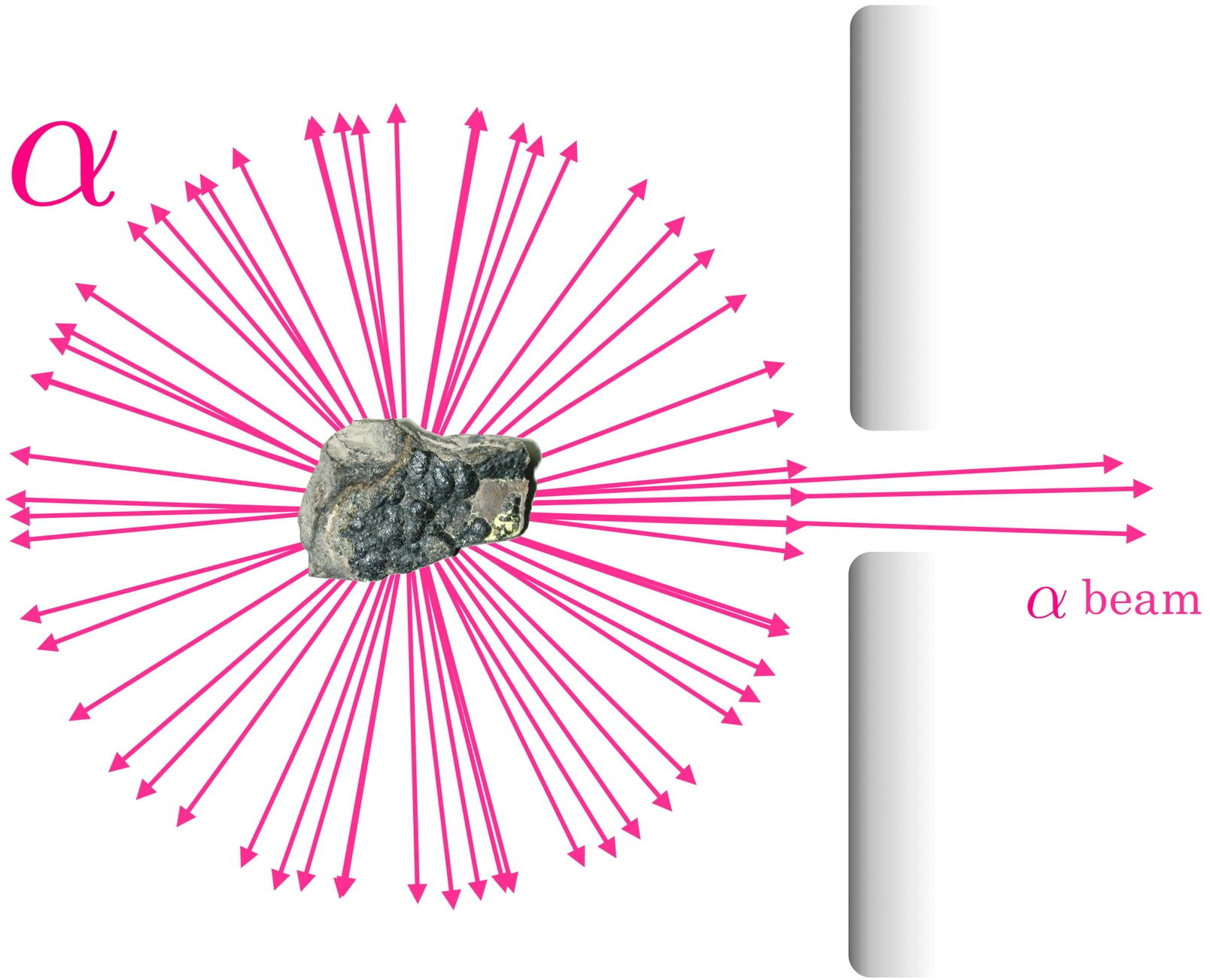
raisins: *specks of – electrons*

Rutherford went back to Britain

1907, Chair of Physics at University of Manchester

made "beams" of alpha particles using highly radioactive sources

Scattering experiments...



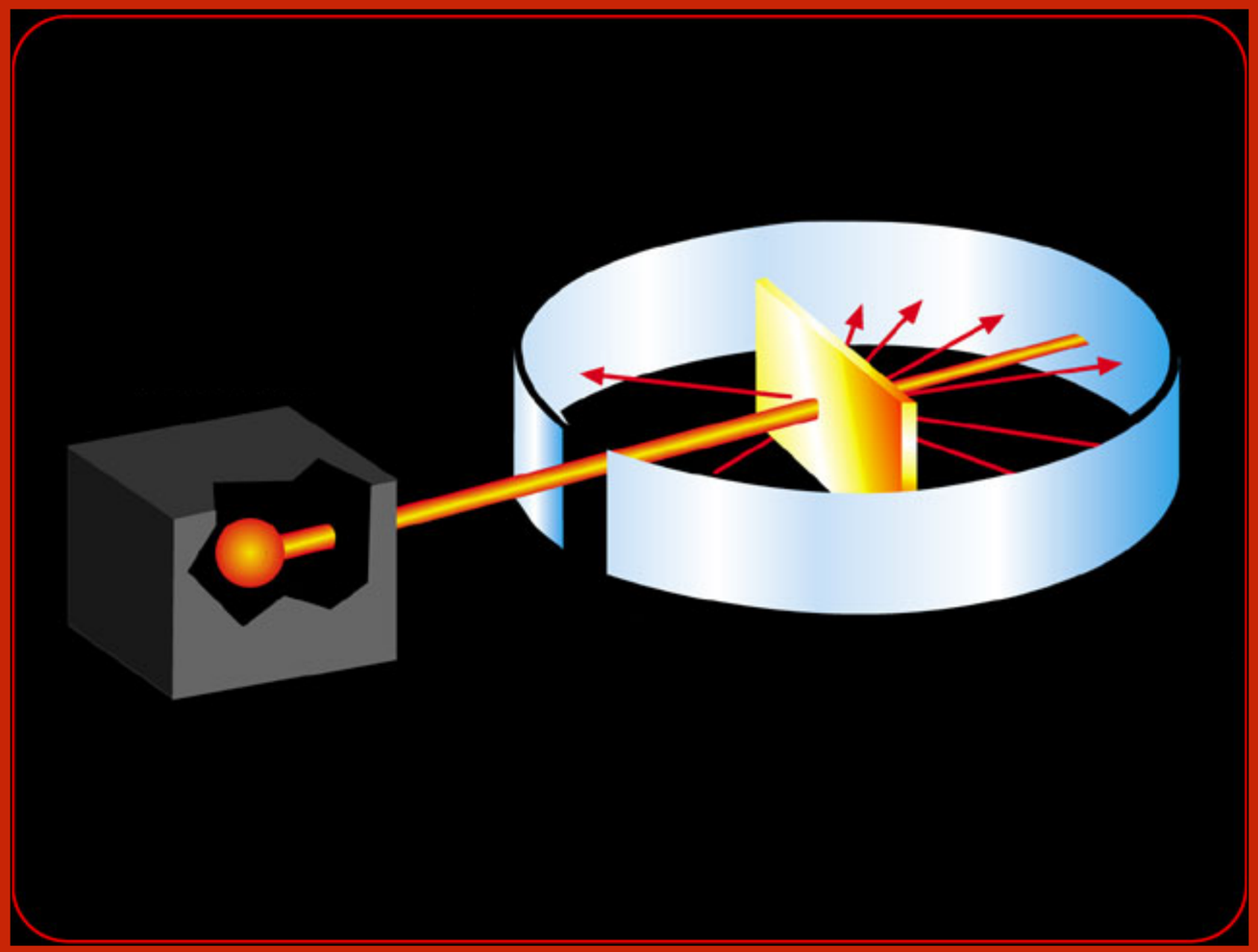
post doc

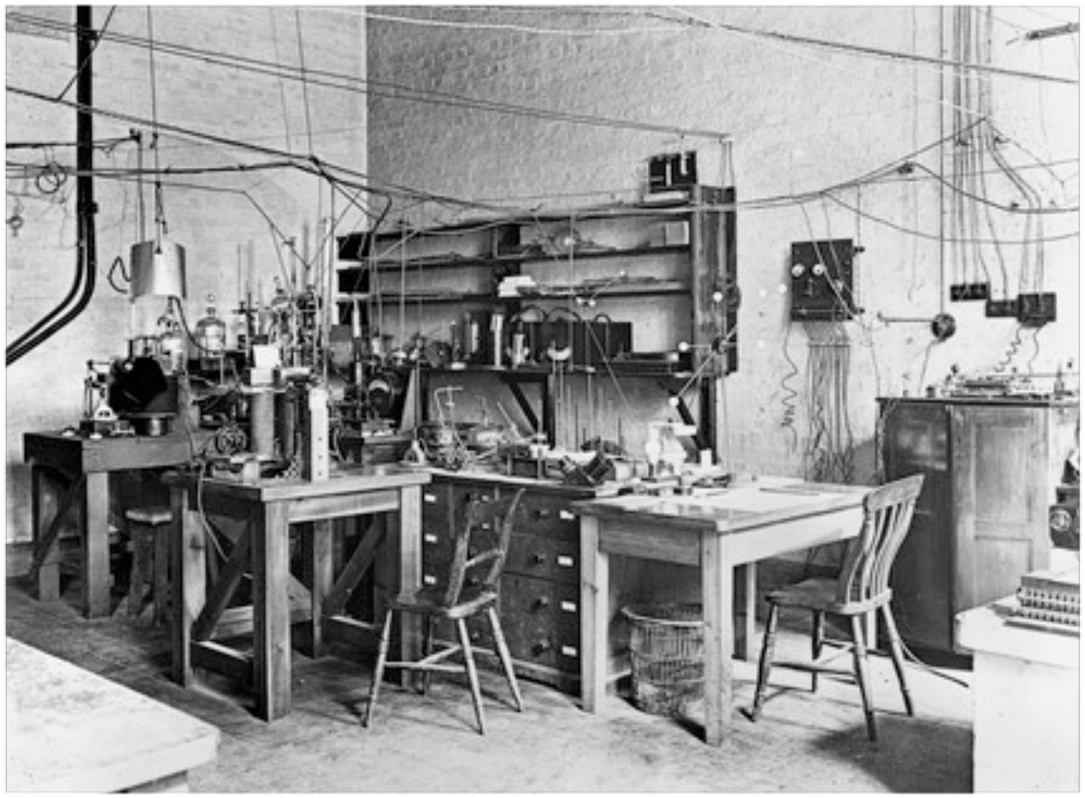
undergraduate student

Hans Geiger and Eugene Marsden studied

“scintillating” sheet

α particle scattering from Gold 1909

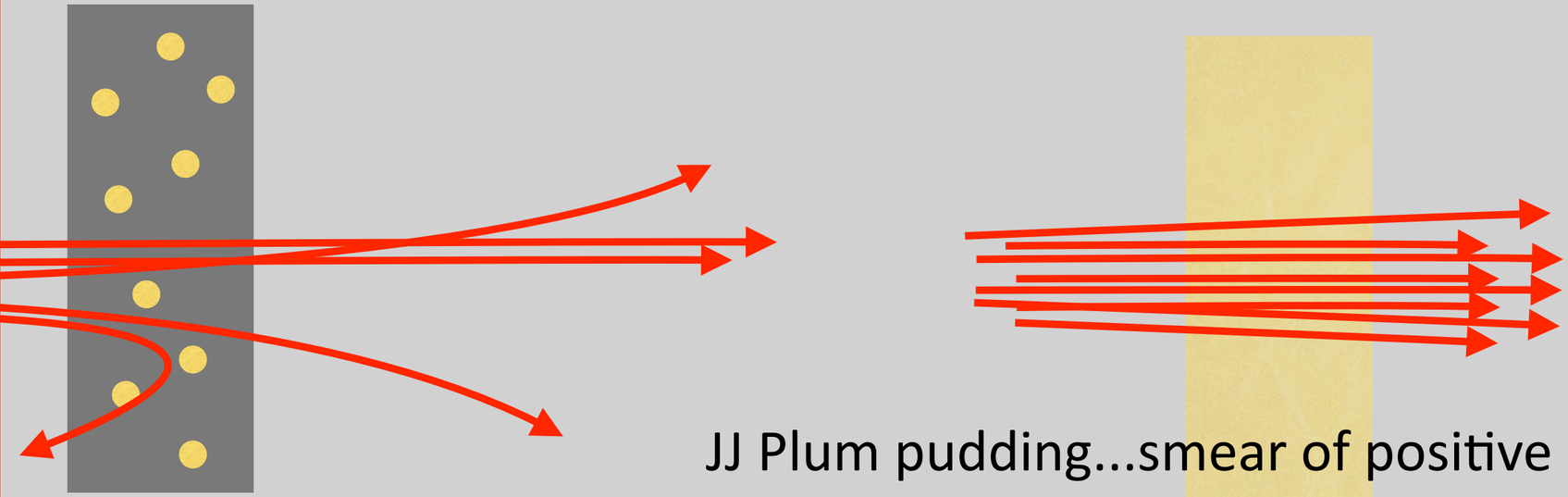





© University of Manchester

“It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back at you.

He had the solution after 2 years of work



JJ Plum pudding...smear of positive charge - tiny individual deflections

the Rutherford Model of the atom:

Matter consists of **hard-cores of positive charge**.

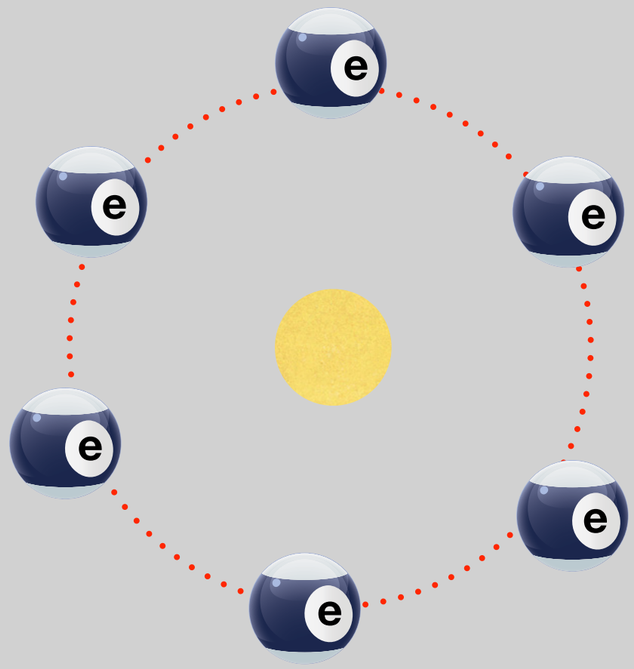
The nucleus. This matched his alpha-scattering data.

The **electrons**? Somewhere around the outside?

he found:

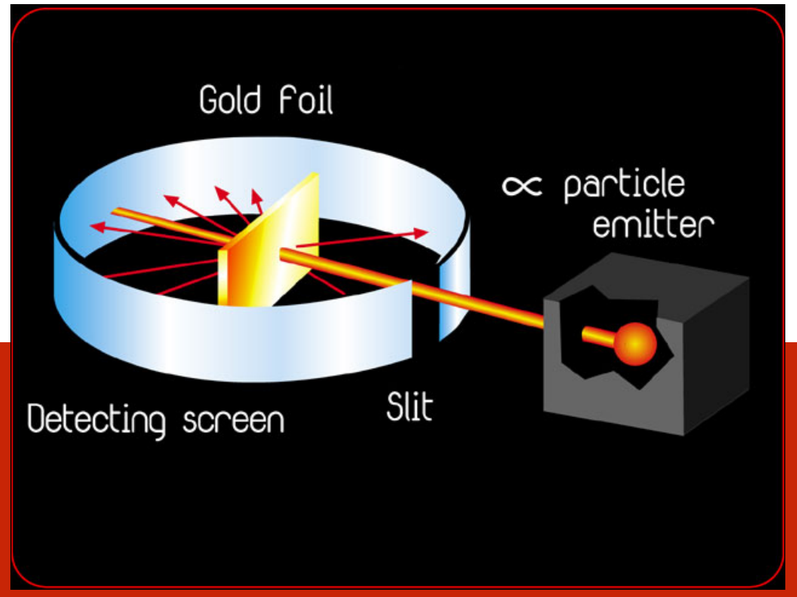
1911: that the Atomic Number was +Ze

and made a model of the atom...



That's problematic, the electrons would accelerate...and radiate.

a spiral of death.

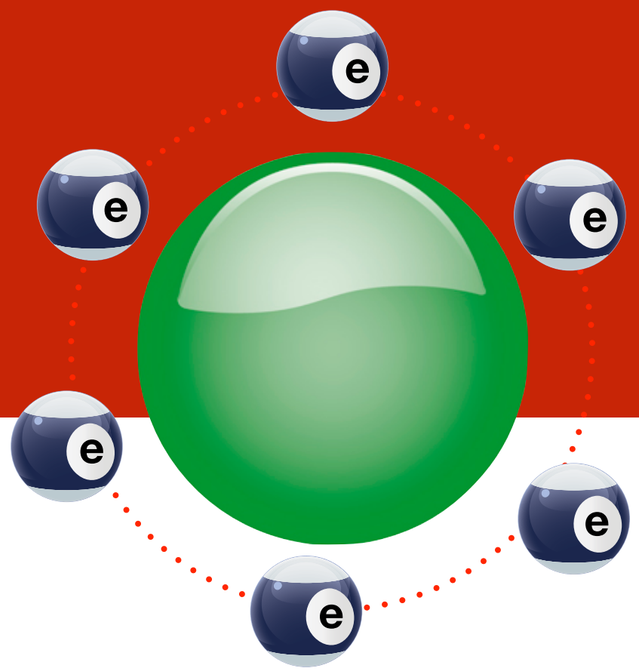


Measuring how often alphas scattered into different directions allowed Rutherford to estimate the size of the nucleus

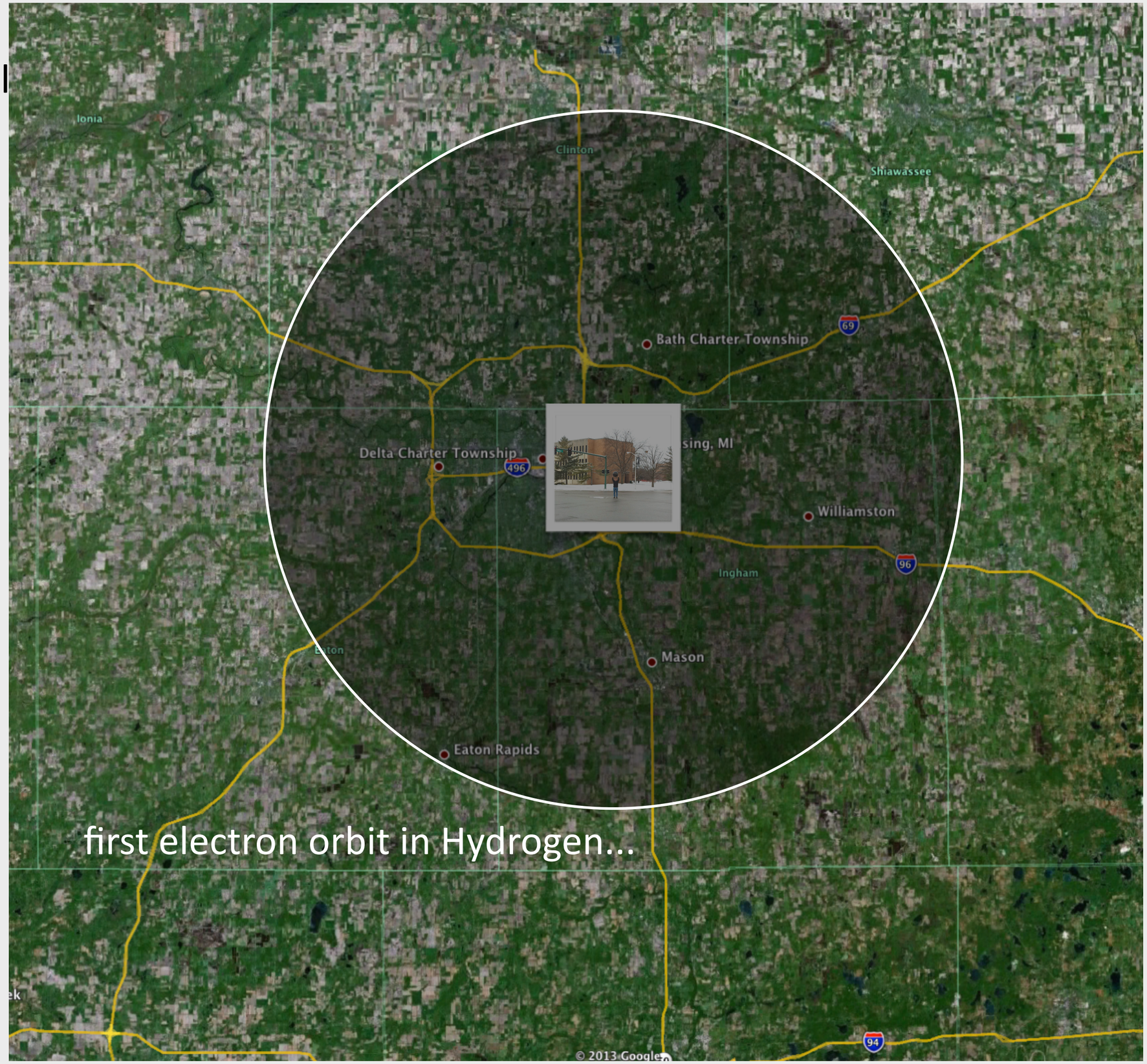
the minimum size of the nucleus is

3×10^{-14} m

atom mostly nothing!



1 meter diameter ball



as a proton...

first electron orbit in Hydrogen...

Ernest Rutherford:

Sir Ernest, 1914

Baron, Lord Rutherford of Nelson, 1931

Died 1937, ashes interred

Westminster Abbey near Newton

Father of Nuclear Physics:

- Discovered: the 3 nuclear decay modes
- Described nuclear decay rates...measured the Uranium chain
- Discovered the hard-core nucleus
- Modeled the atom
- First to deliberately transmutate an atom
- discovered & named the proton
- Predicted the existence of the neutron...w/ Chadwick, 1935
- Predicted fission

into this walks

one of the more imaginative physicists in the 20th century

Niels Bohr

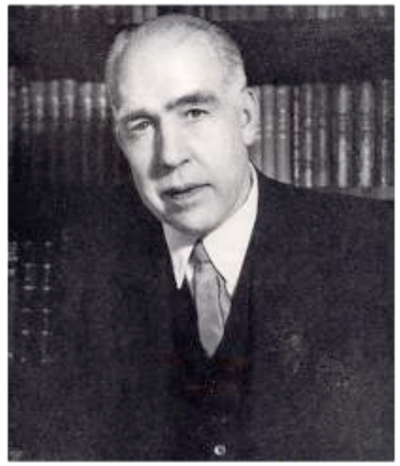
1913

Niels Bohr

1885 – 1962

a talker.

> The opposite of a profound truth may very well be another profound truth.



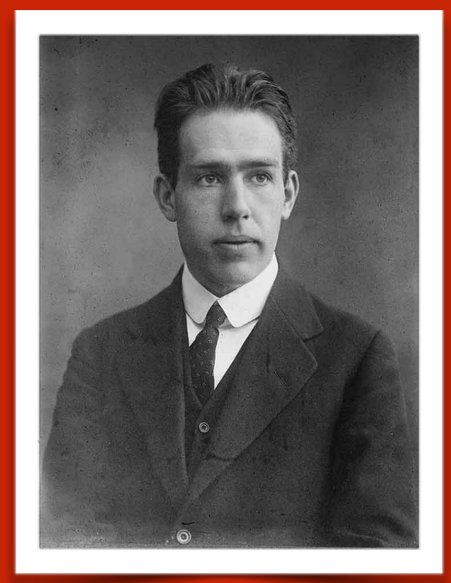
Rutherford not disposed kindly

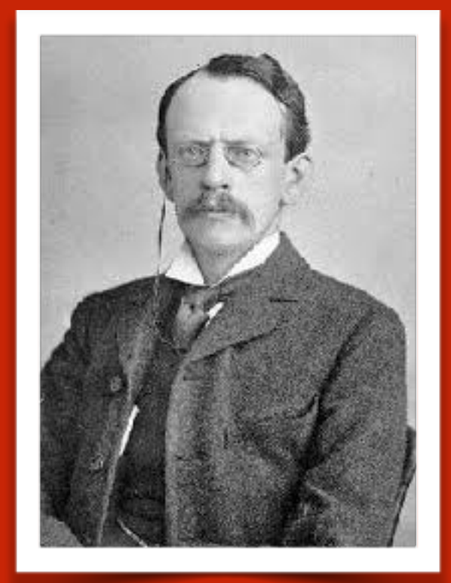
towards theoretical physicists

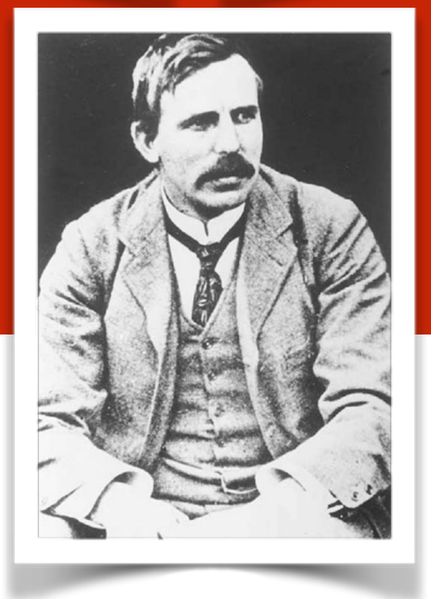
but he saw something in young Bohr

and in 1912 hired him to Manchester

away from a grumpy JJ Thompson







In 1913 Bohr simply asserted

That at atomic distances...

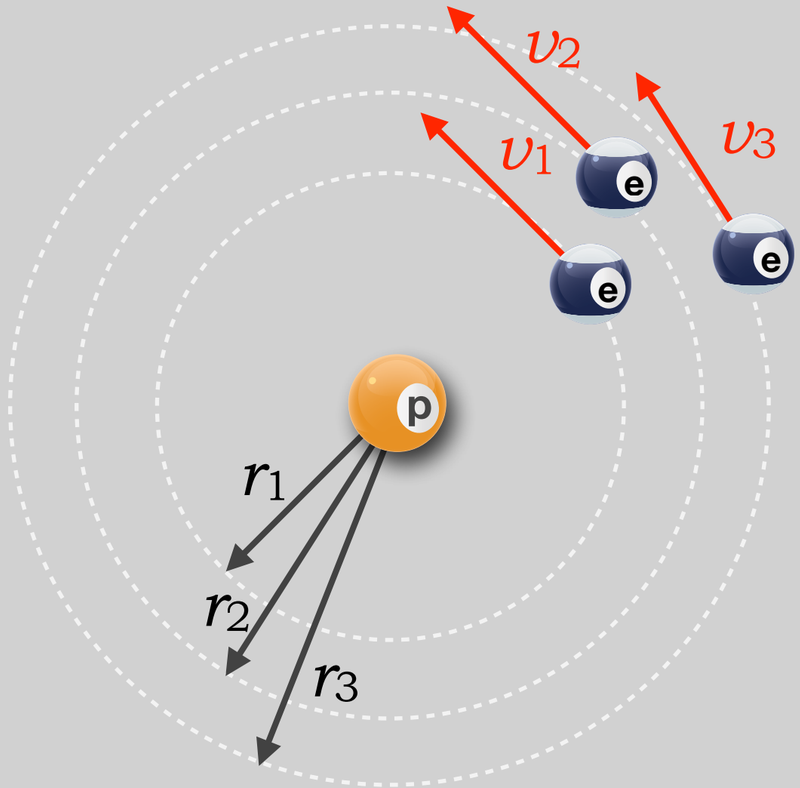
there are electron orbits that simply don’t radiate - “stationary states”

fixed “quantized” orbital radii and orbital velocities

The Bohr Model

for any atom with one electron on the outside shell

The Hydrogen Atom (the proton not yet discovered!)



With each radius and velocity...comes a distinct energy.

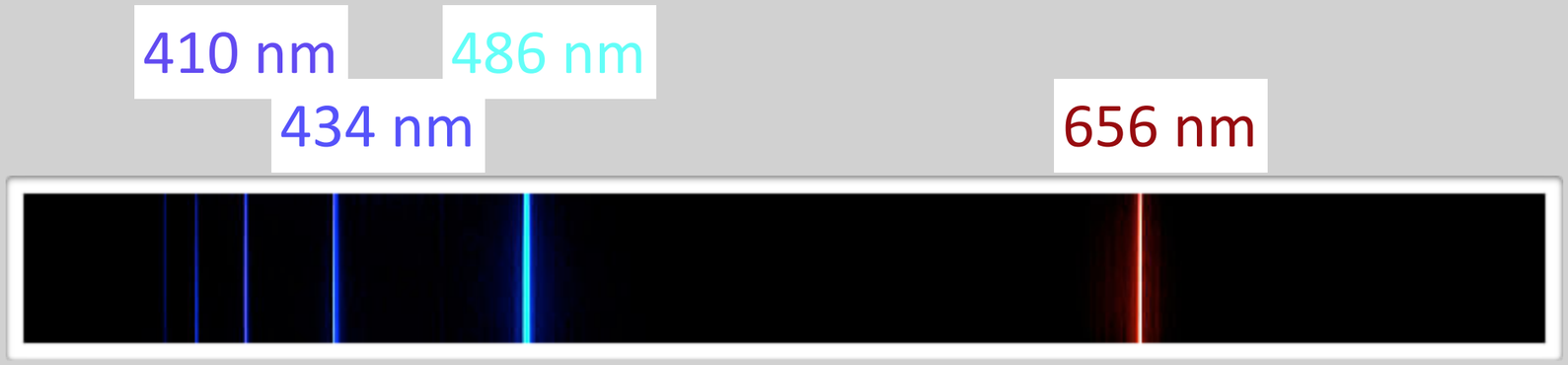
$$E_n = -\underbrace{\frac{1}{2}\frac{4\pi^2 k^2 e^4}{h^2}\frac{1}{n^2}}_{\text{just numbers...}} = -C\left(\frac{1}{n^2}\right)$$

$$E_n = -(13.6)\frac{1}{n^2}\ \text{eV}$$

Hydrogen spectrum

already known

but apparently not by Bohr!



light emitted by Hydrogen was at particular wavelengths...

in 1885 Johann Balmer played and found a pattern:

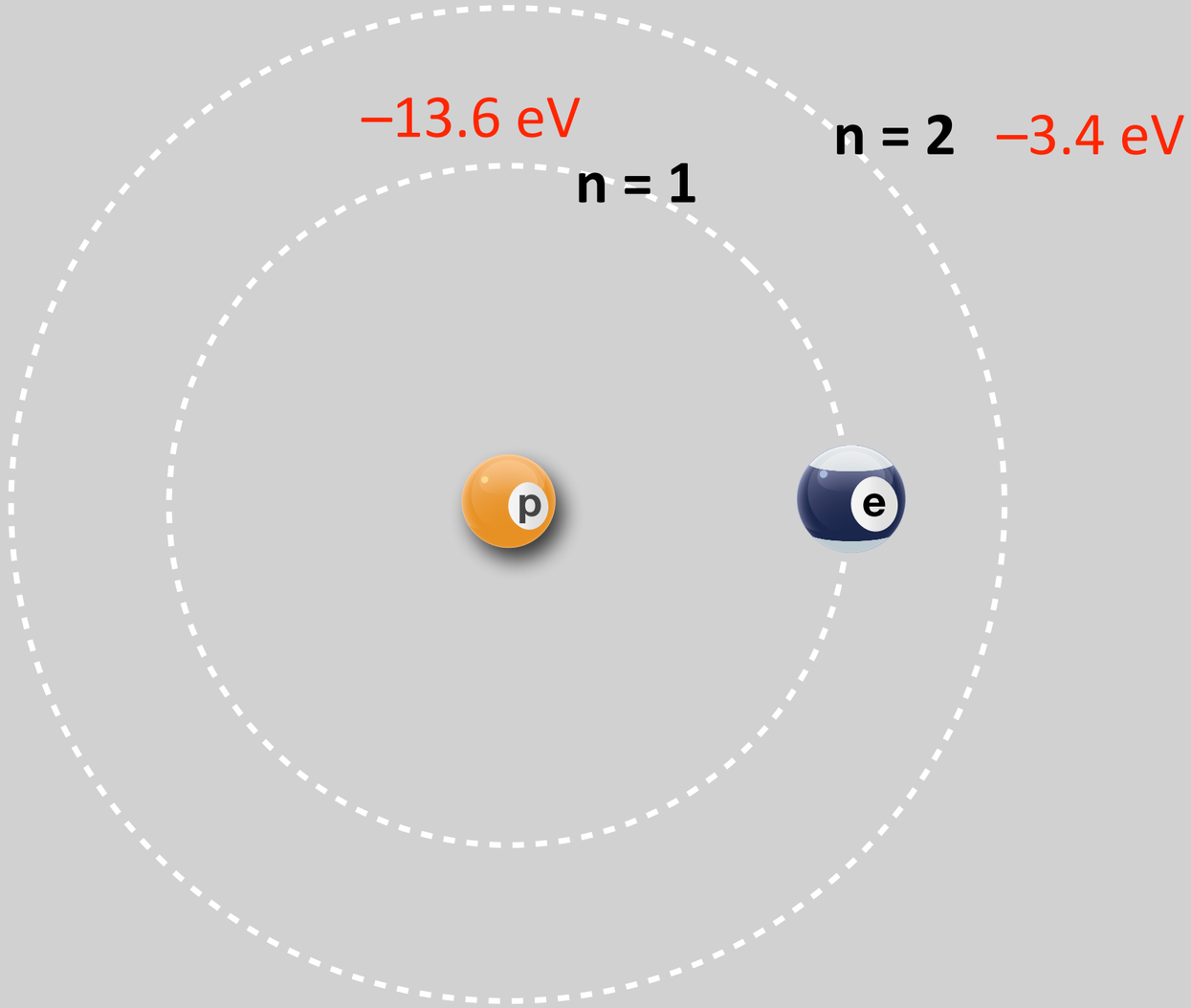
$$\frac{1}{\lambda} = R_H \left(\frac{1}{2} - \frac{1}{n^2} \right) \quad \text{n = 3, 4, 5...}$$

$1.09737 \times 10^7\ \text{m}^{-1}$

When Bohr learned of the old Balmer idea

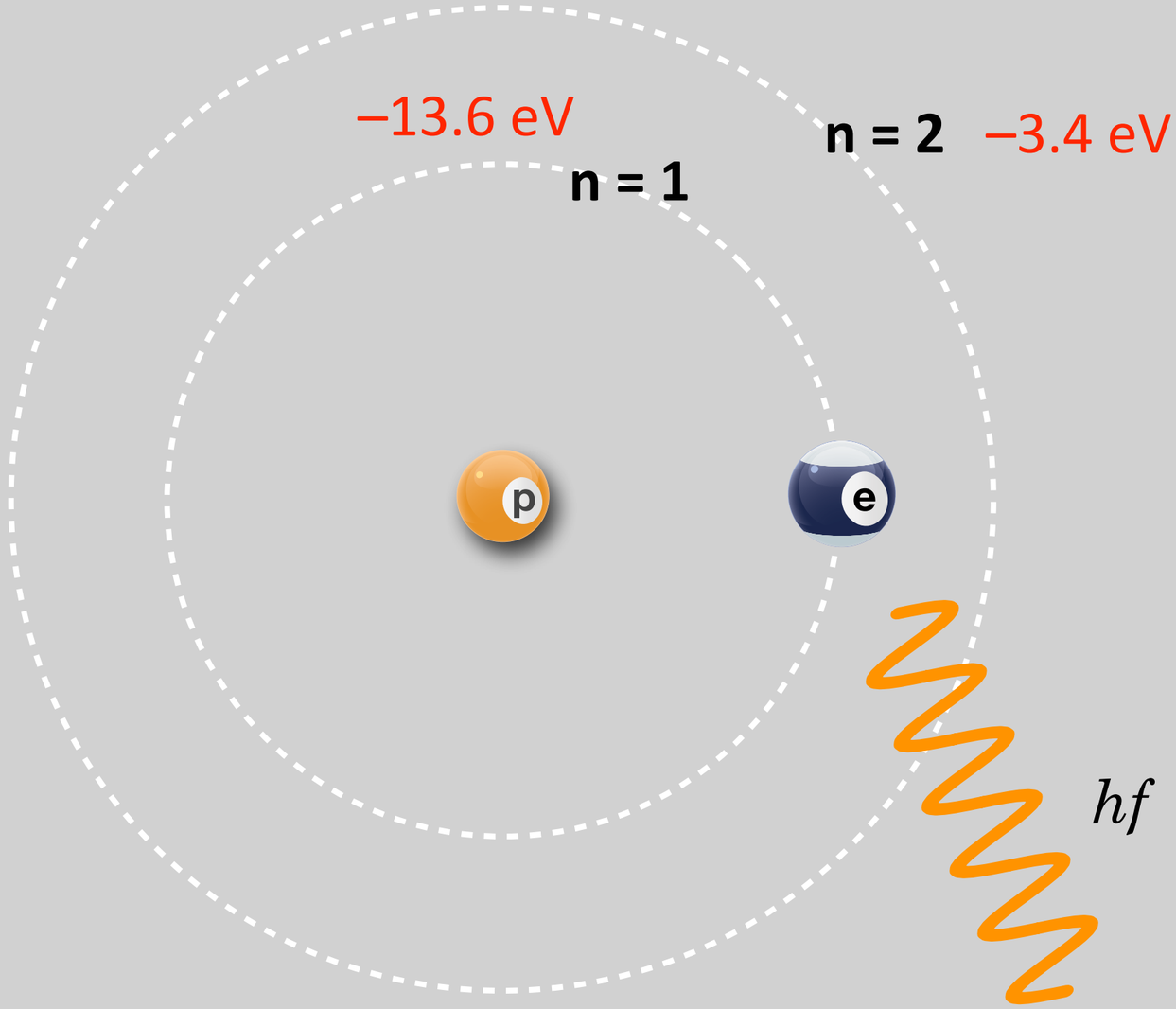
aha! moment

energy differences could matter



the magic:

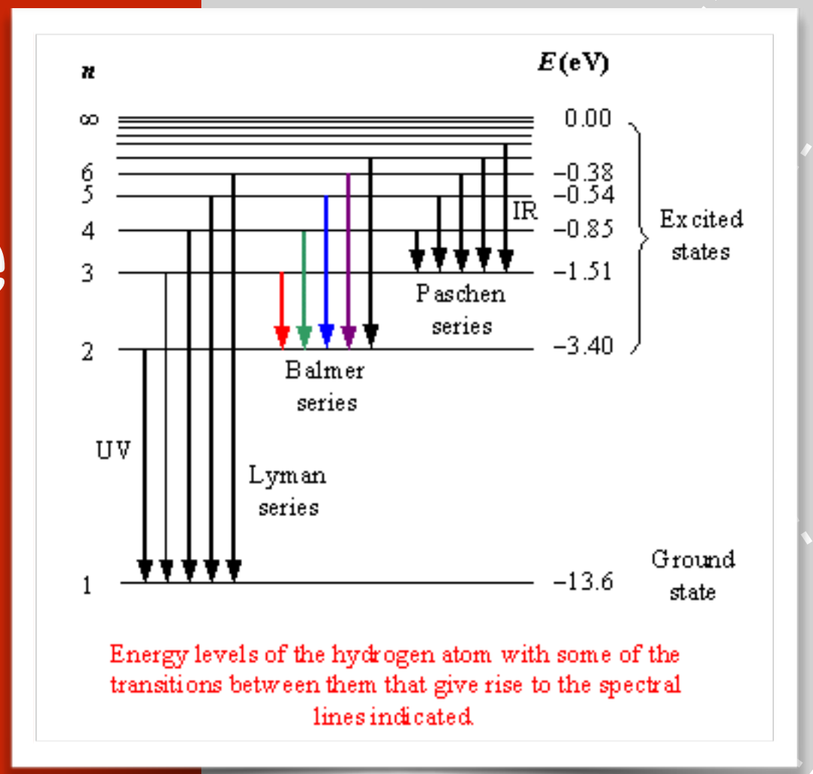
the idea of an atomic transition



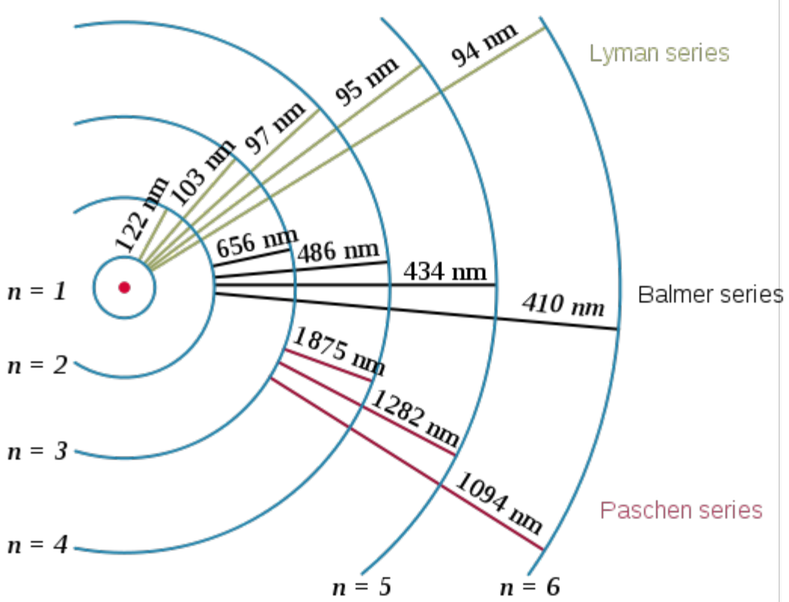
The idea: transition of electrons results in the released energy of a photon...of a particular energy

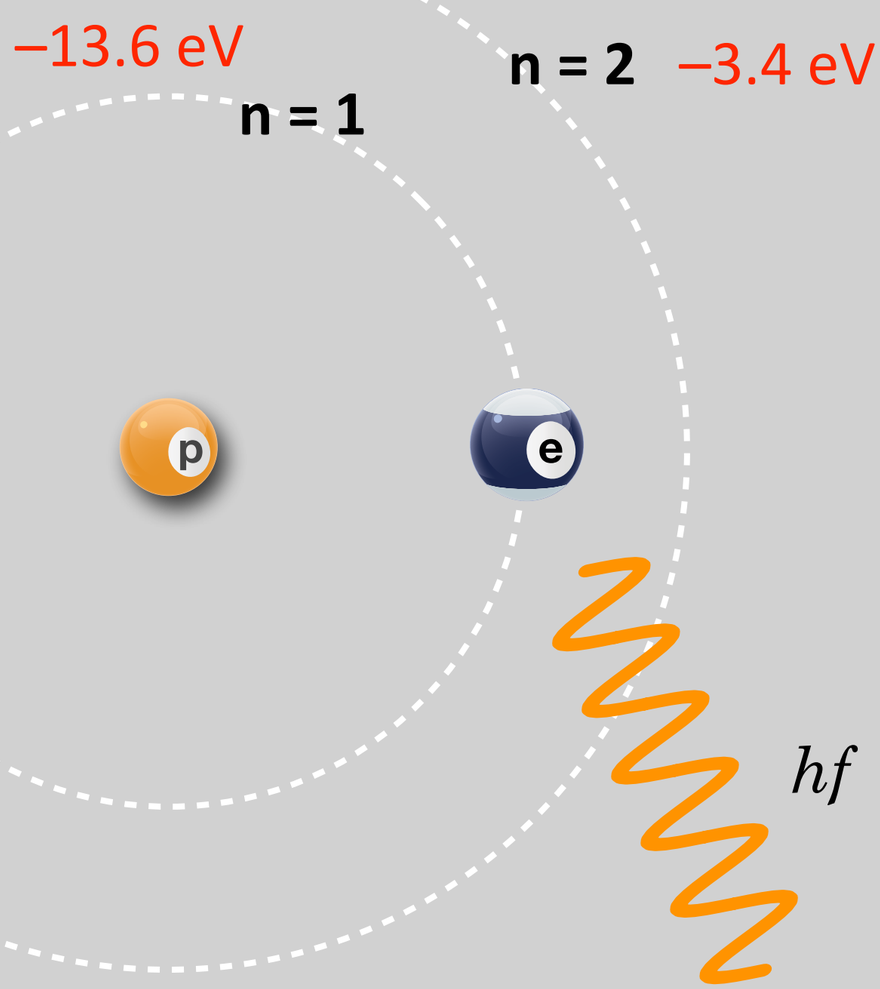
imagine his surprise

1913: his way.



Energy levels of the hydrogen atom with some of the transitions between them that give rise to the spectral lines indicated.





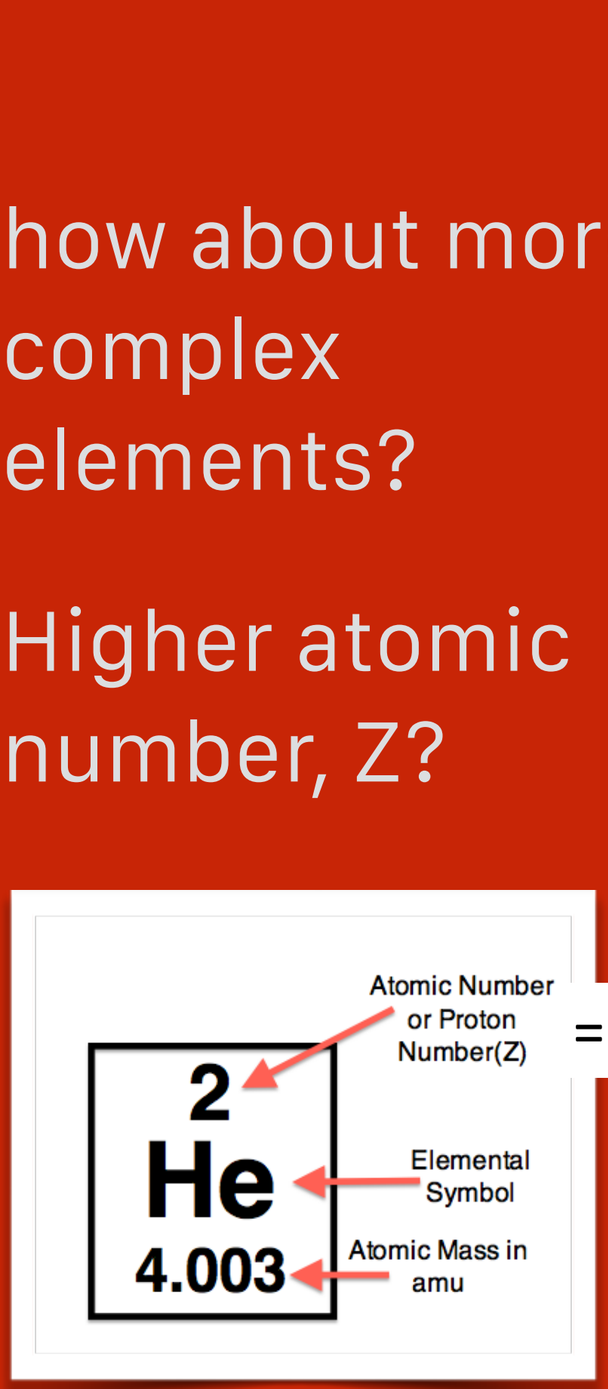
$$E_2 - E_1 = (13.6\ \text{eV})\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = hf$$

$$E_2 - E_1 = 10.1\ \text{eV} \longrightarrow \lambda = 122\ \text{nm}$$

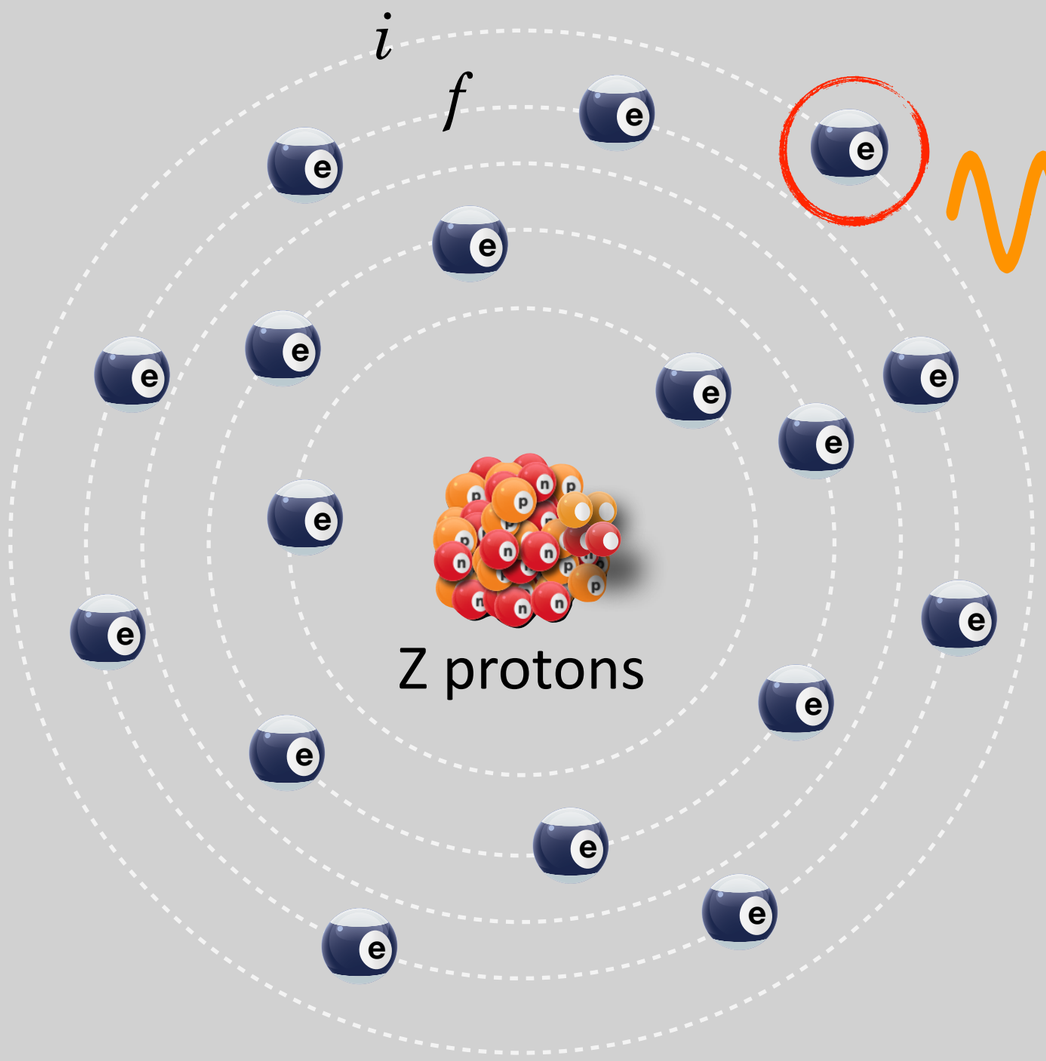
hydrogen, fine

how about more complex elements?

Higher atomic number, Z?



= # of electrons also!



lots of electrons, but as long as there's one lone one..the Bohr Formula still works.

$$E_f - E_i = -\frac{1}{2}\frac{4\pi^2 k^2 Z^2 e^4}{h^2}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) = -hf$$

Go looking for new elements....

yup, 1922

actually with Einstein's delayed prize

particle: **proton: 1914, Rutherford & Geiger**

symbol:	p
charge:	$+1e$
mass:	$m_p = 1.6726\times10^{-27}$ kg
spin:	1/2
category:	fermion, hadron, baryon