hi

Day 20, 02.04.2019

Quantum Mechanics 3

I got nothin’

Stones week

Opening Day Happened!

housekeeping

Gotta come to class

question about anything?

I'll make a movie for you:

Grades to date: Projects, quizzes, notes in a pdf in the slides area

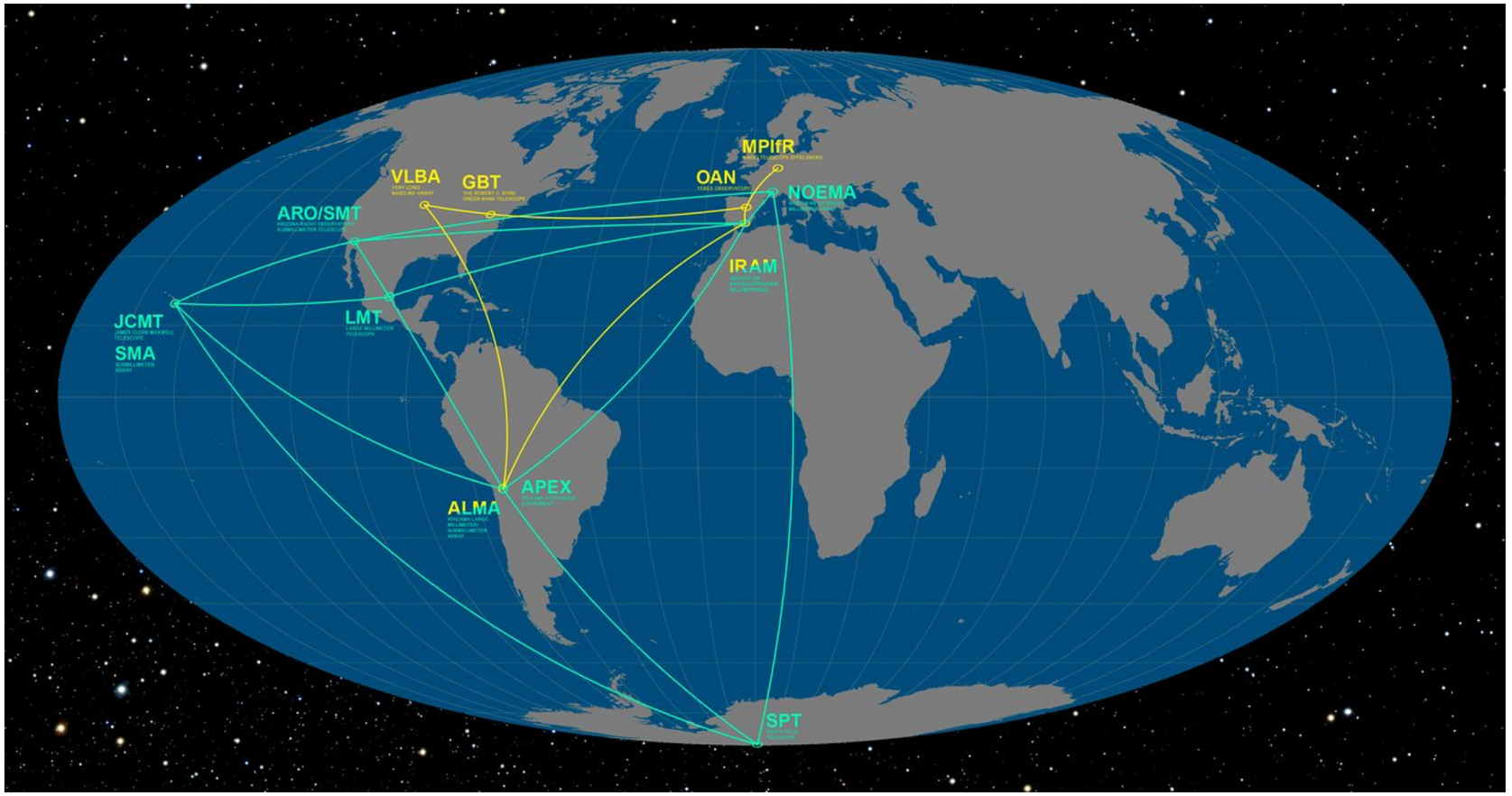
the rest of your grades are in LON-CAPA or MasteringPhysics

Totally forgot to create the "redshift homework problem" that I said I would.

this Saturday

Event Horizon Telescope (EHT)

effectively a radio telescope the size of the earth



Press conference scheduled for 10 April

https://www.nytimes.com/video/science/100000003725182/peering-into-a-black-hole.html?emc=edit_au_20150609&nl=afternoonupdate&nlid=68634180

March 2019

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
24	25	26	27	28	1	2
3	4	5	6	7	8	9 HW6
10	11	12 lecture	13	14 lecture	15 HW6 due	16 HW7
17 HW7 due	18	19 lecture	20	21 lecture	22	23 HW8
24	25	26 lecture	27	28 lecture	29 HW8 due	30 HW9
31	1	2 lecture	3	4 lecture	5 HW9 due	6 HW10

spring break

Eastern Time Time Zone

Honors project

How's it going?

Document #2 is uploaded

https://qstbb.pa.msu.edu/storage/QS&BB2019/Homework_Projects/honors_project_2019/

It assigns data files to each

Two due dates:

report on the day of the Final

text file of data by April 26

you'll see in document #2

Index of /storage/QS&BB2019/Homework_Projects/honors_project_2019

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ISP220_inspirationaltalk.pdf	2019-03-10 12:42	4.3M	Portable Document Format file
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MinervaInstructions2_2019_1.pdf	2019-03-22 15:50	122K	Portable Document Format file
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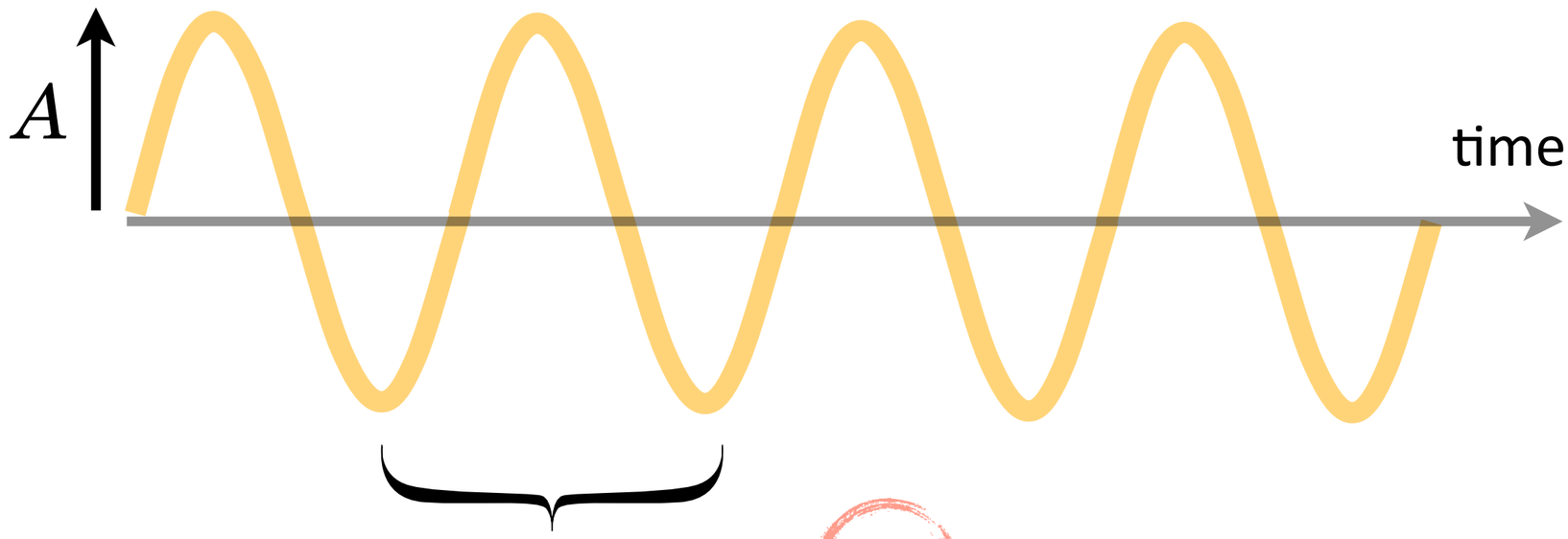
just some facts, Ma'am

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

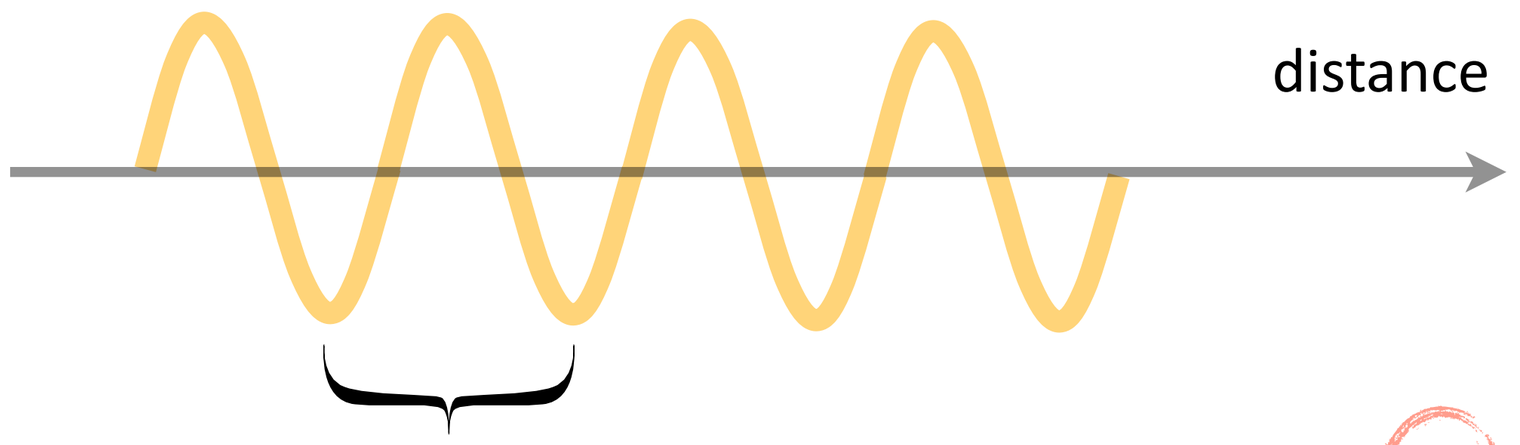
"Intensity" is ~ A^2



time to repeat: "Period," T. seconds

rate of repetition: "Frequency," f. (Hz)

$$f = \frac{1}{T}$$



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

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

jargon alert:

Black Body Radiation

refers to:

A thermal absorber that perfectly absorbs all wavelengths of EM radiation and emits according to its temperature

entomology:

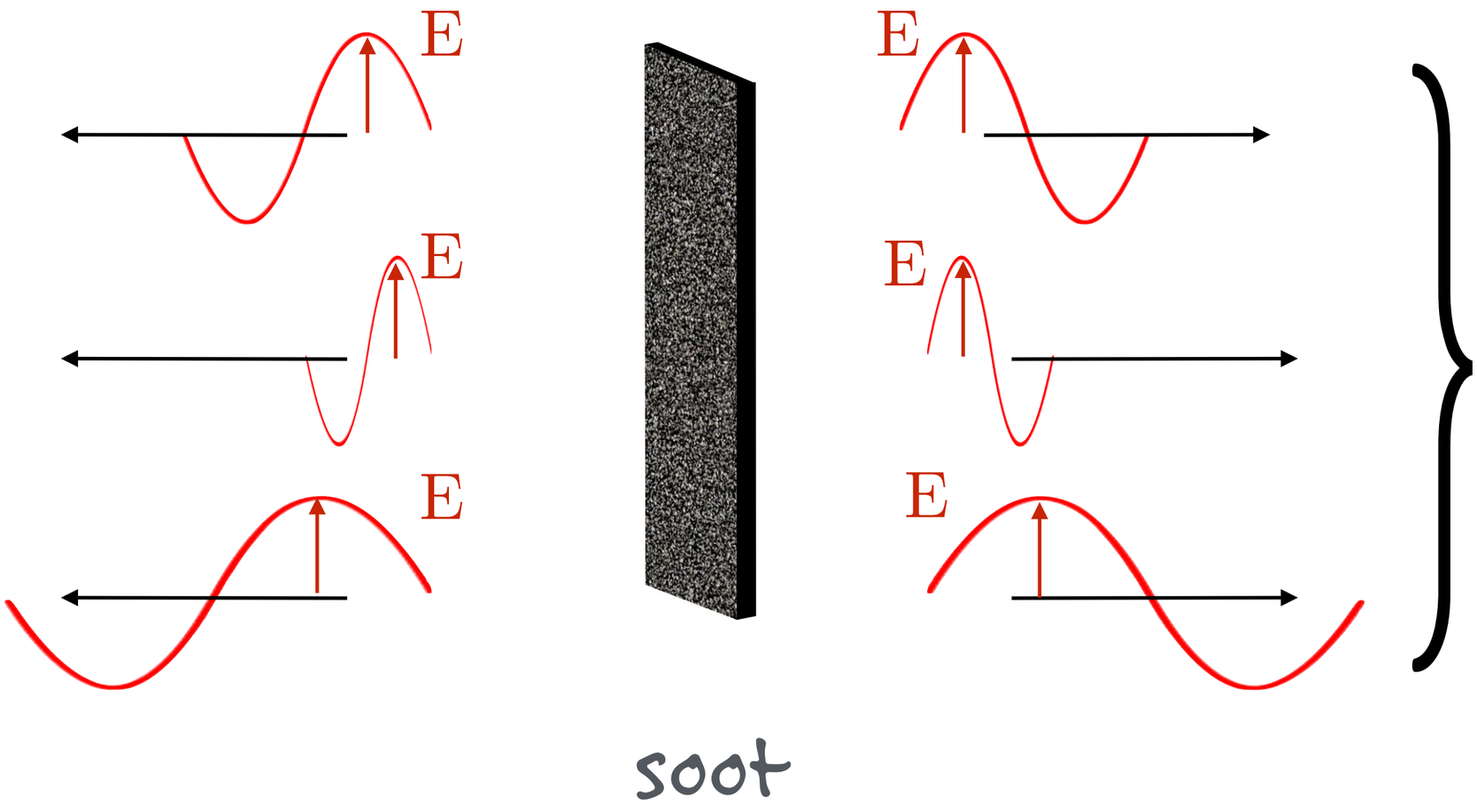
“black” in the sense of a perfect absorber...no reflection

example:

A cavity with a hole, a near-black object, a star...

it's still radiating

absorbs <u>all</u> radiation and emits <u>particular</u> radiation

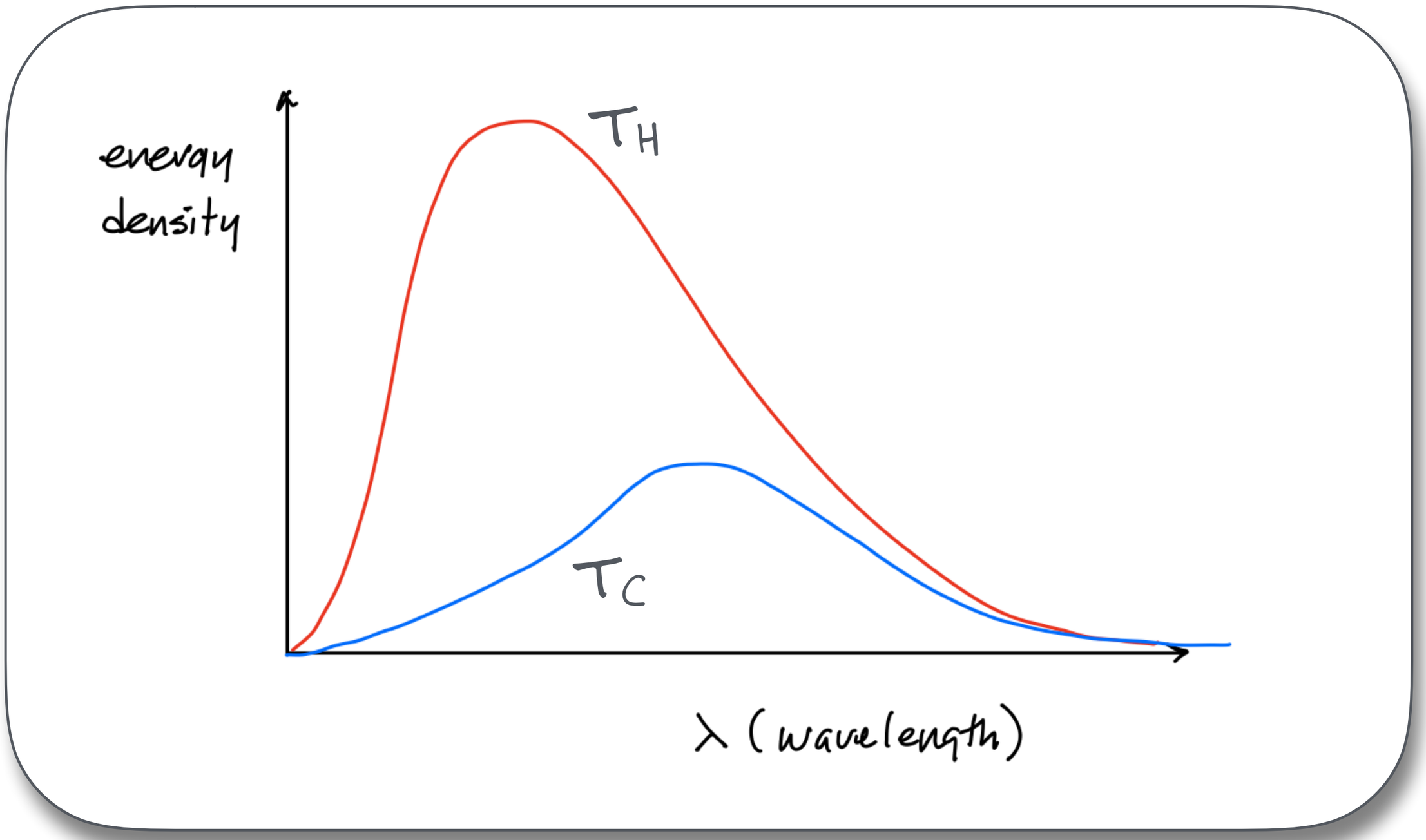


soot

the amount at each wavelength:

- depends on temperature
- universal for all materials

make your fingers think

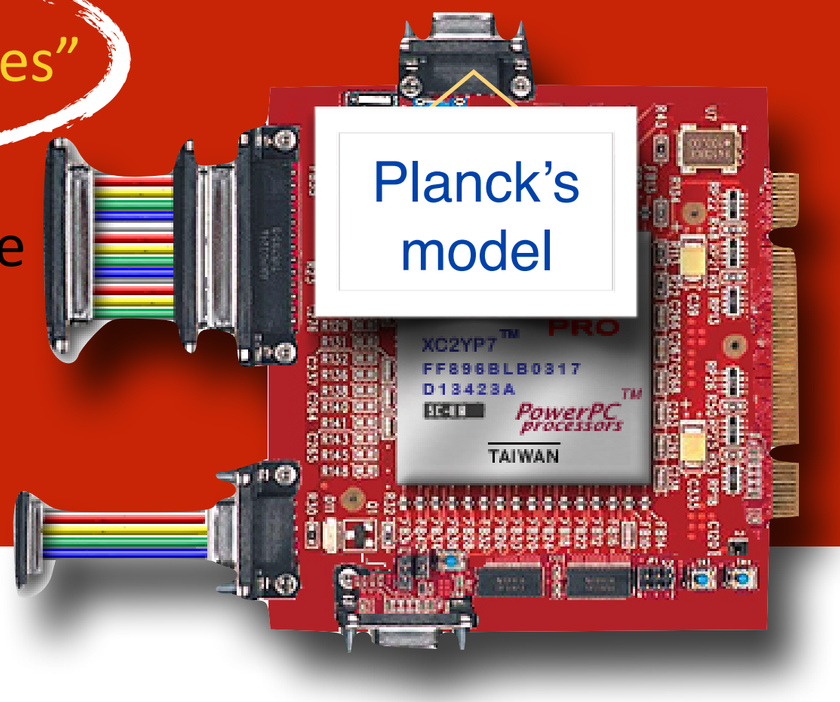


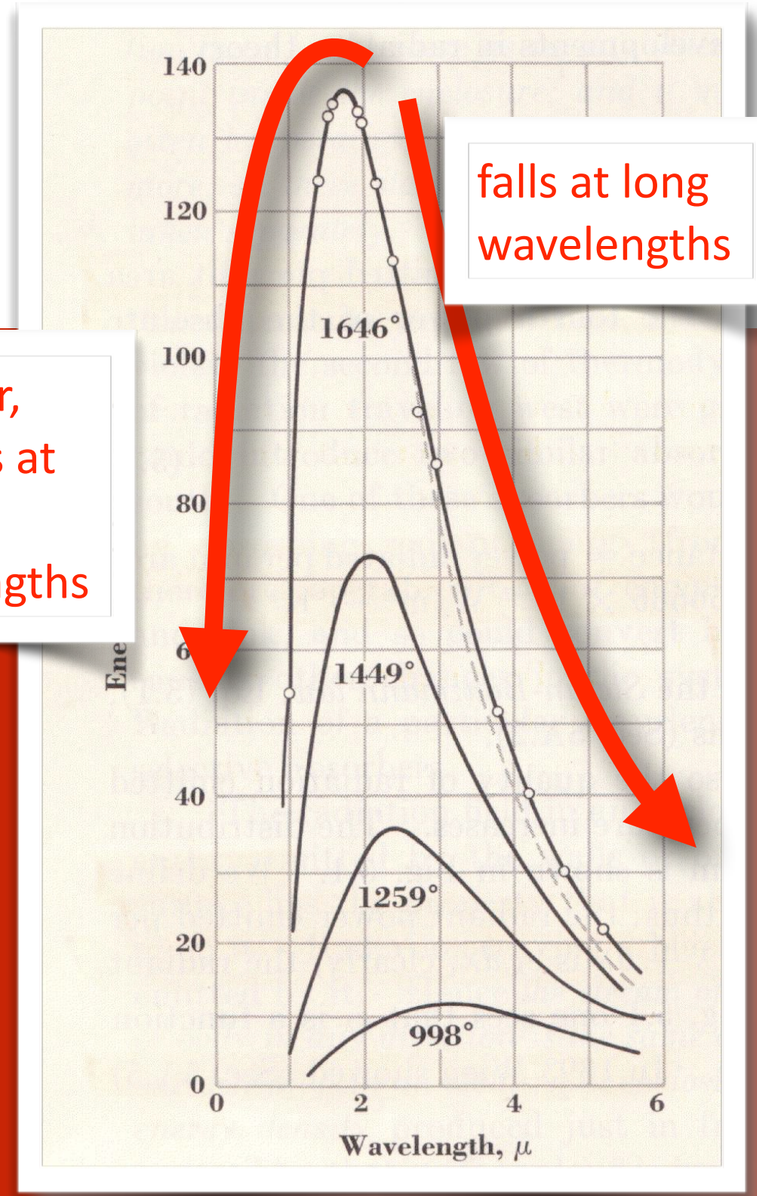
Planck could only get a solution

if he restricted energies of emitted electromagnetic radiation

"**bundled** energies"

temperature





long wavelength →

← high frequency

$$v = \lambda f$$

relation alert: **Planck's Law**

refers to: $E = hf$

Energy of radiation comes in a discrete amount for each frequency

example: photoelectric effect

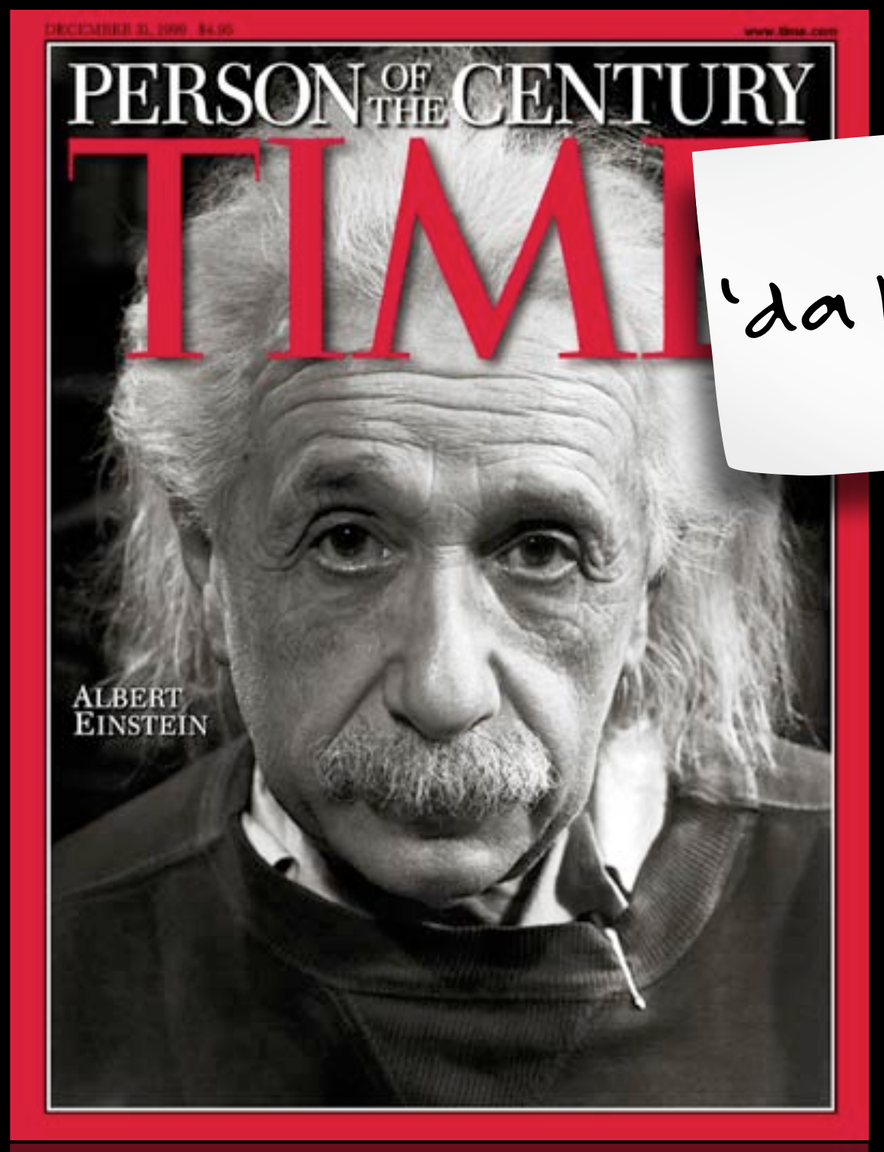
constant of nature:

Planck's Constant, h

value: $h = 6.62606896(33) \times 10^{-34}$ J-sec

units: Energy - time

usage: everything at atomic and smaller sizes

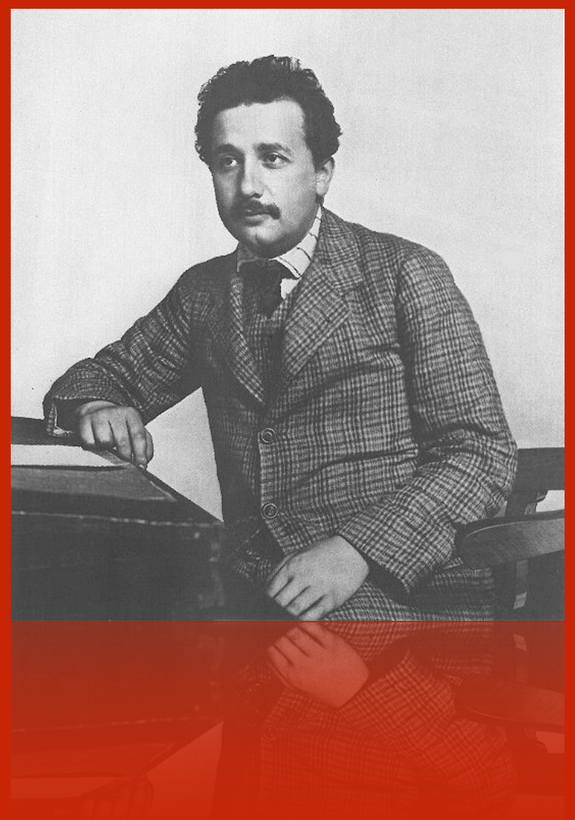


'da Man

He's Back

Einstein said:

in that famous 1905 year



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

It is a statement about light (electromagnetism)

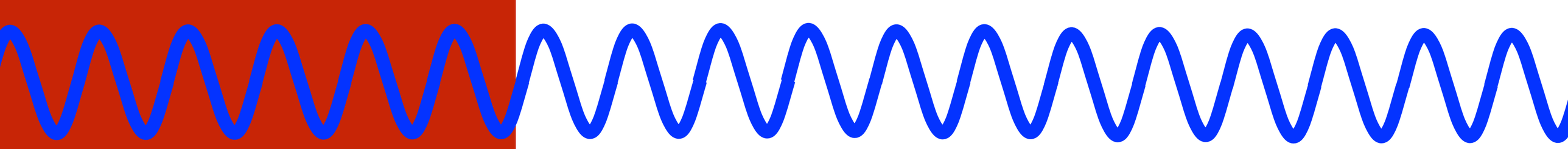
Light is itself "quantized"

....as particles:

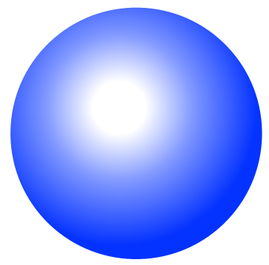
these particles are now called: "photons," γ they have no mass

hold the phone.

A wave is EVERYWHERE
& light is a wave:



A particle is HERE:

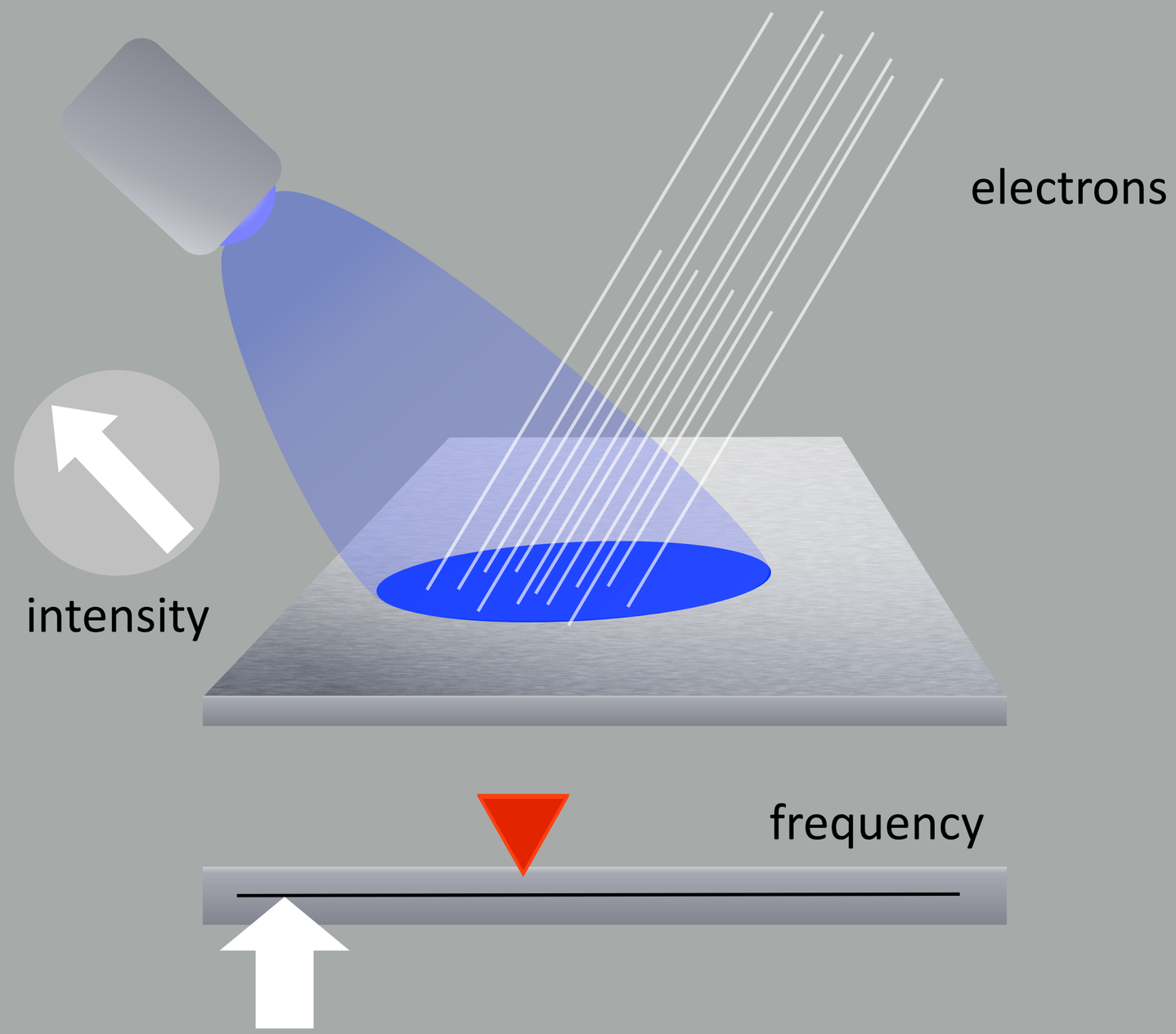


How could things so opposite be combined into one reality?

Einstein was motivated by experiment: "Photoelectricity"

found by Hertz in his confirmation of Maxwell's waves

Ultraviolet light causes electrons to stream from surface of some metals



The facts:	**The light-wave expectation:**
1. no electrons <u>until a particular frequency</u> *then, with higher frequency they come out with more energy*	huh?
2. raise the intensity...get <u>more</u> electrons	expect <u>higher energy</u> electrons

photoelectric effect

everywhere:

photodiodes

smoke detectors, CD players, remote controls...

photocells

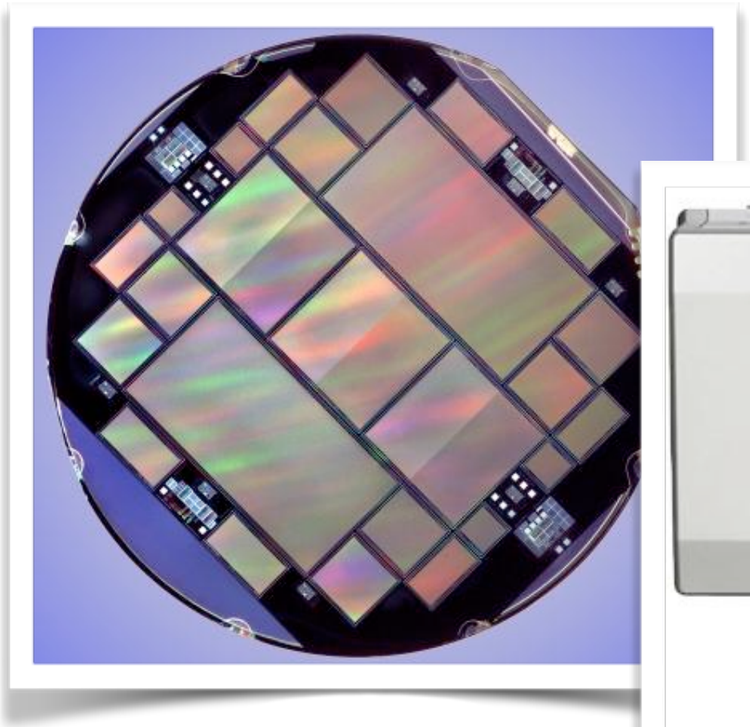
packed into "pixels" and arrays of pixels:

CCDs (charged coupled devices)

The facts:	The light-wave expectation:
1. no electrons until a particular frequency *then, with higher frequency they come out with more energy*	huh?
2. raise the intensity...get more electrons	expect higher energy electrons

53

that's a current



remember the formula

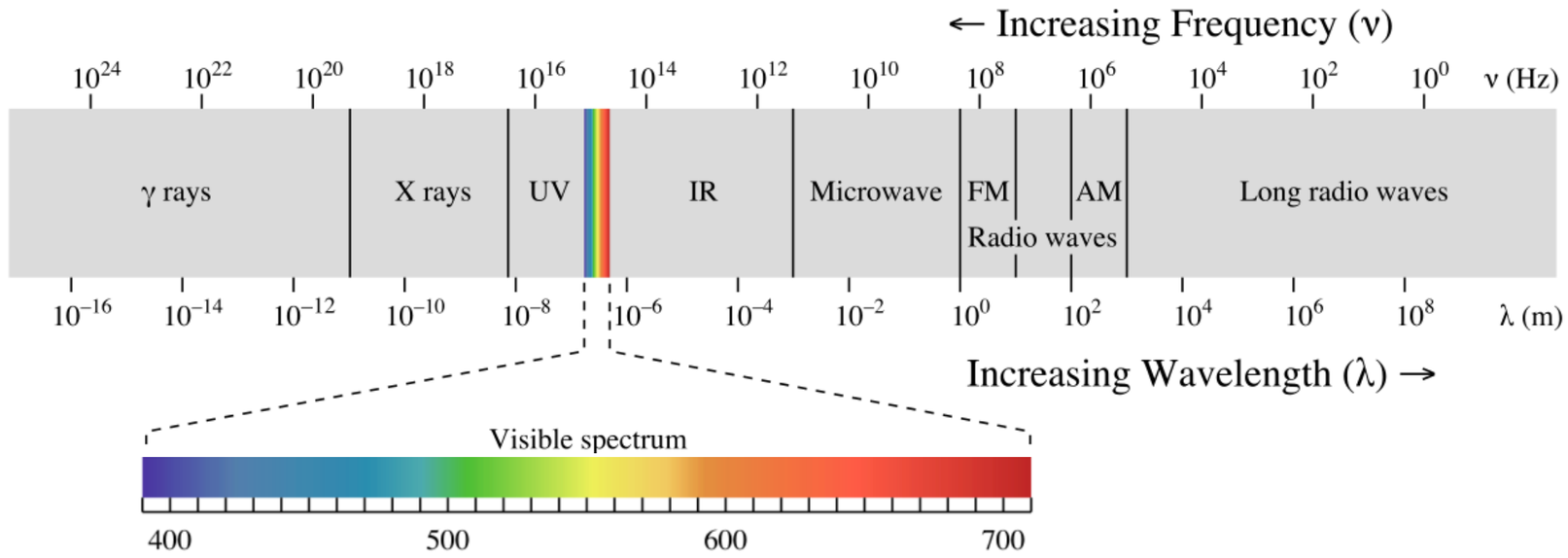
$$E = hf$$

the higher the frequency

the higher the energy

the lower the energy

the lower the frequency



remember about waves: $v = \lambda f$

$$f = \frac{v = c}{\lambda}$$ for light

$$E = \frac{hc}{\lambda}$$

the larger the wavelength

the smaller the energy

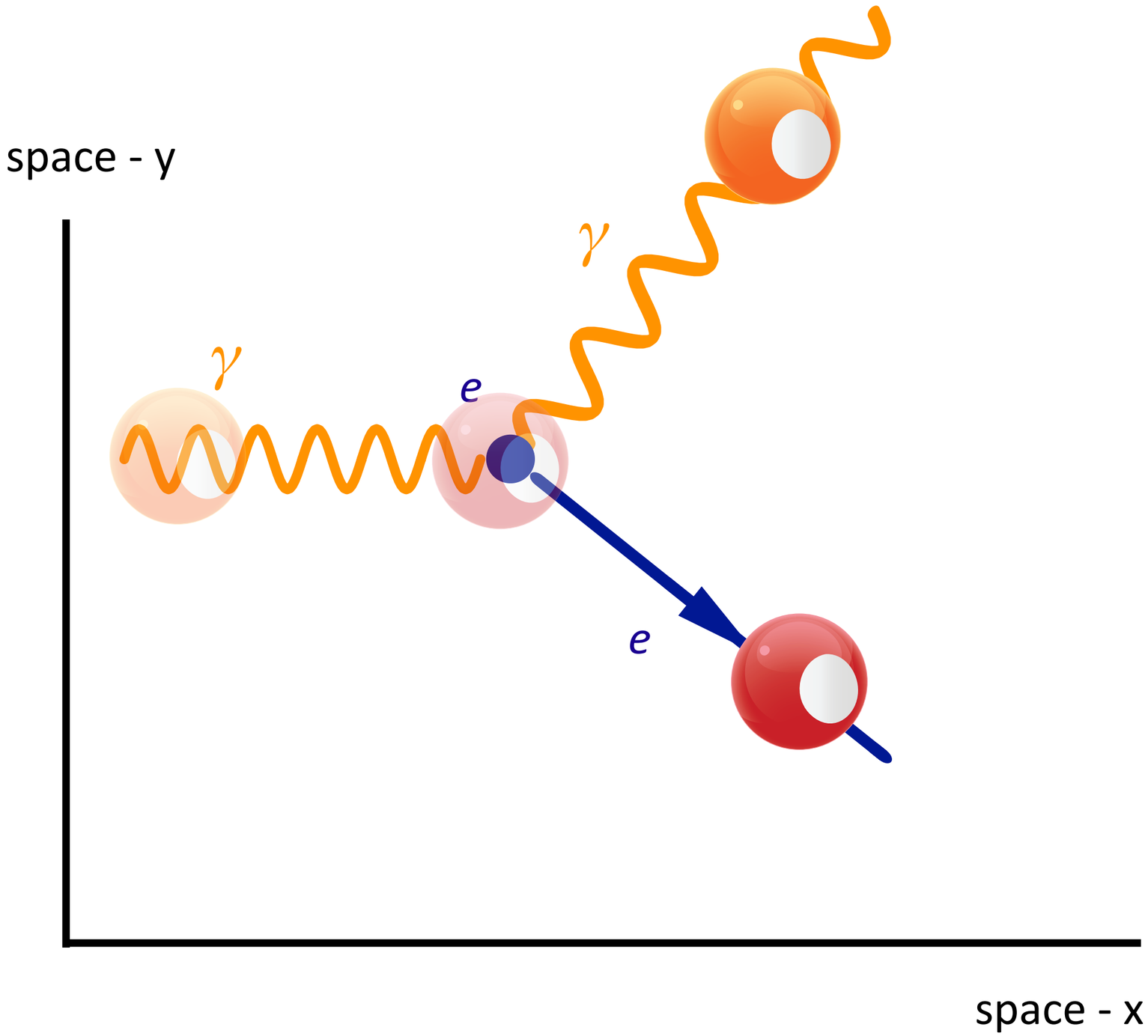
the larger the energy

the smaller the wavelength

Compton scattering

Space diagram

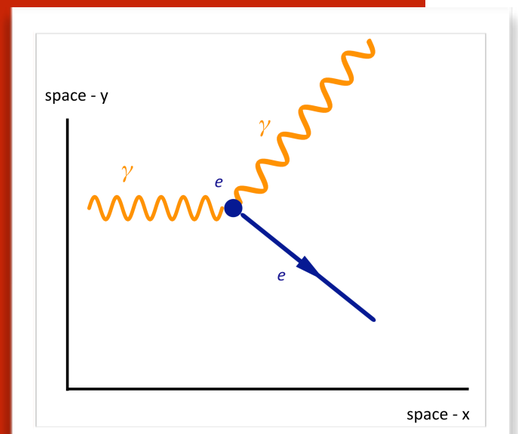
$$\gamma + e \rightarrow \gamma' + e'$$



Compton scattering

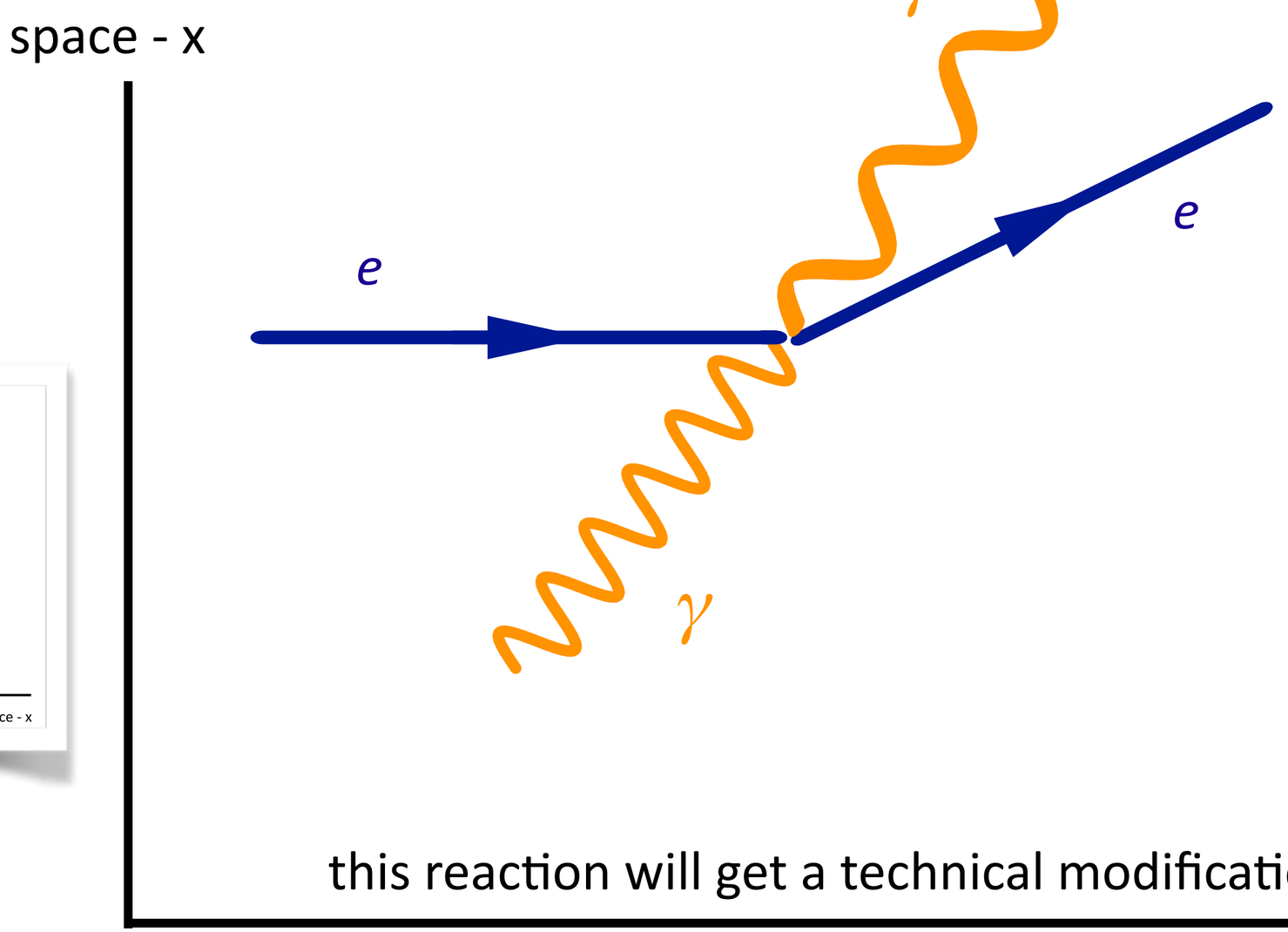
spacetime diagram

aka, *Feynman* diagram



draw the Feynman diagram for Compton Scattering

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



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

wavelength is the key

look at the relative sizes of openings and barriers compared to the wavelength

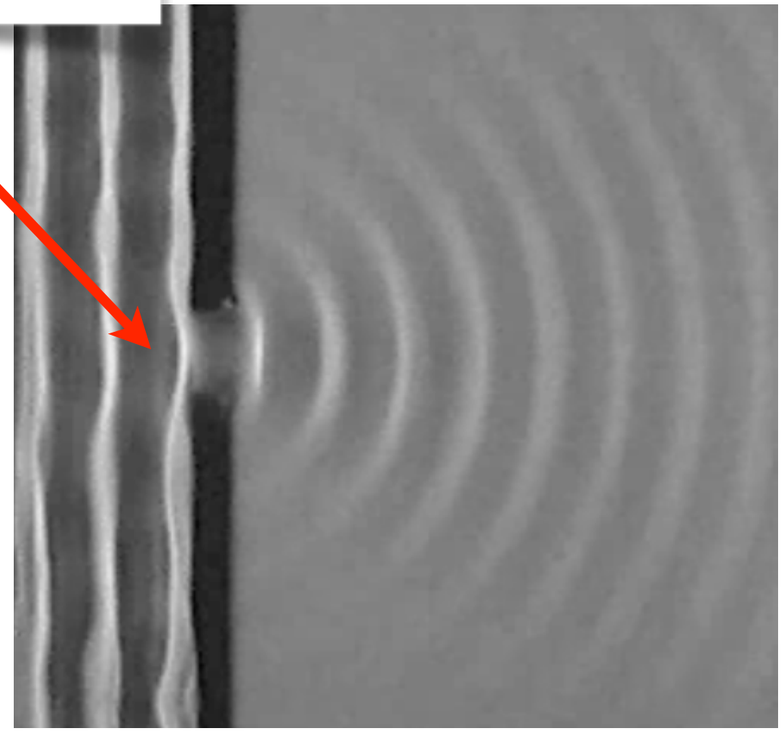
First, think about water waves, then about light waves.

a plane wave impinging on a gap

like 1 "tap"

a gap of about a wavelength-width

plane waves



like the 1-tap image

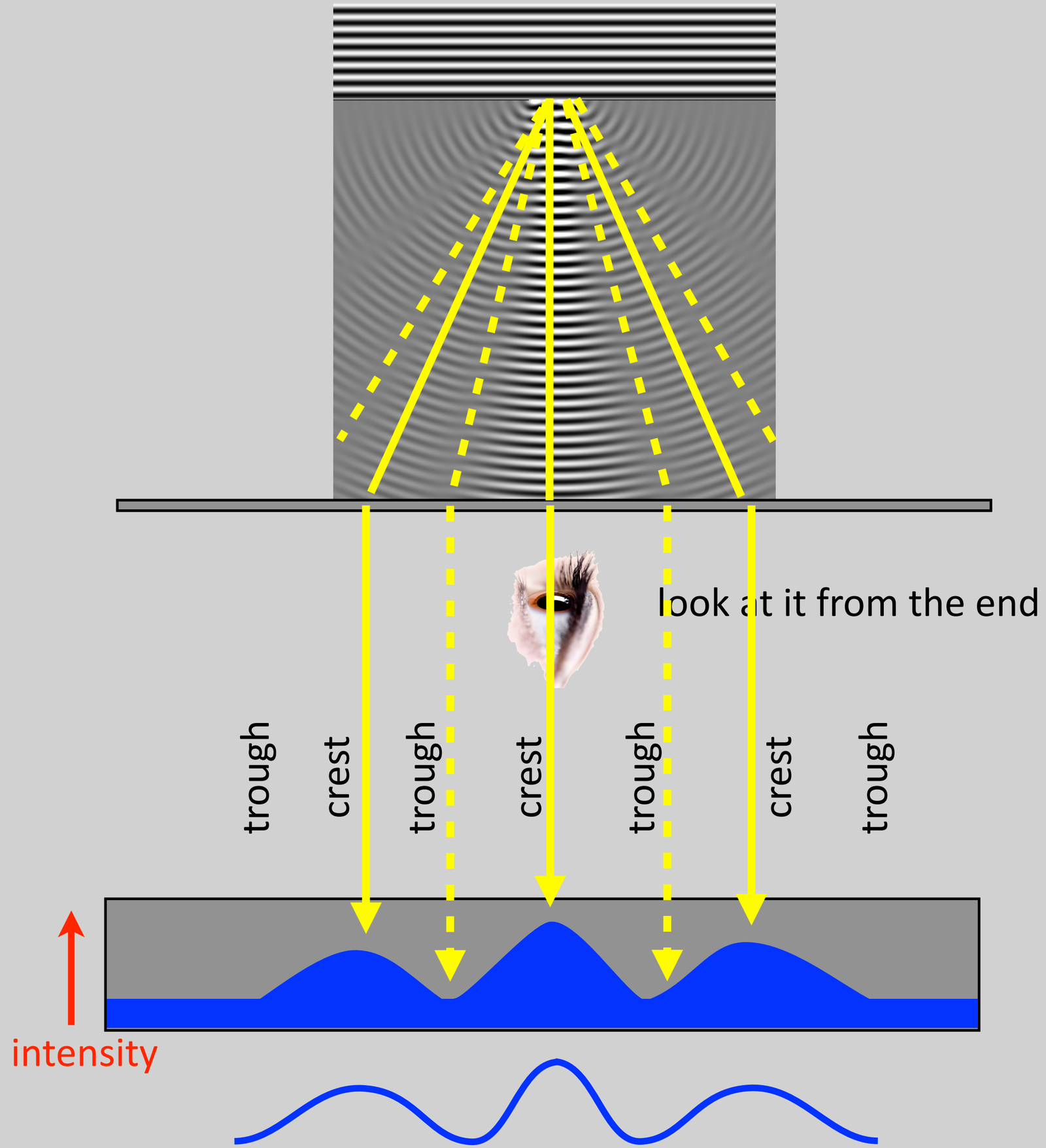
Another smoking gun of wave-behavior
(as opposed to particle behavior)

This is diffraction

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

look at it from:

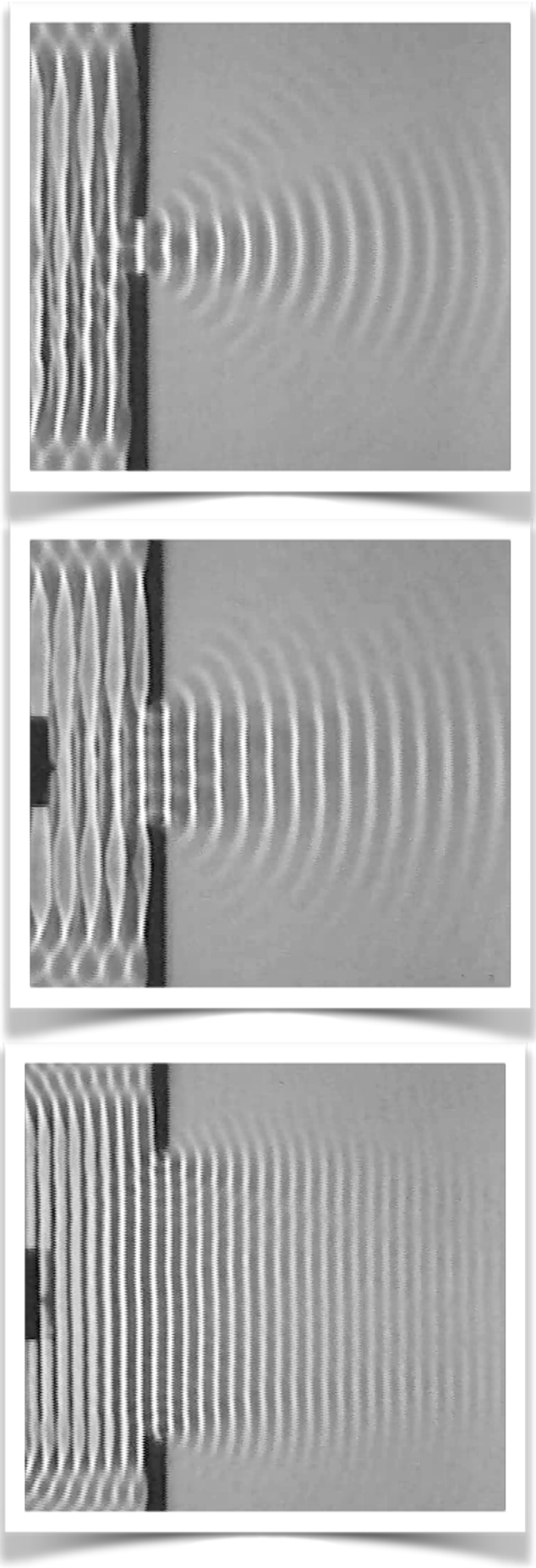
the side where the waves are coming at you



the relative size of the gap

determine the apparent diffraction amount

increasing gap relative to wavelength

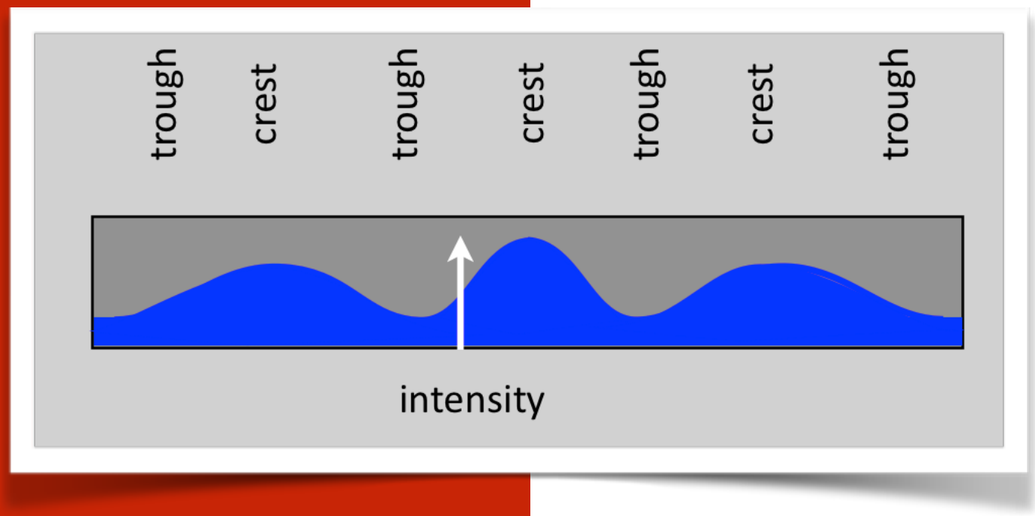


that’s why you can’t see around doors

this is for water

close to the slits

for light...many, many wavelengths away from the slits...stuff happens



diffraction

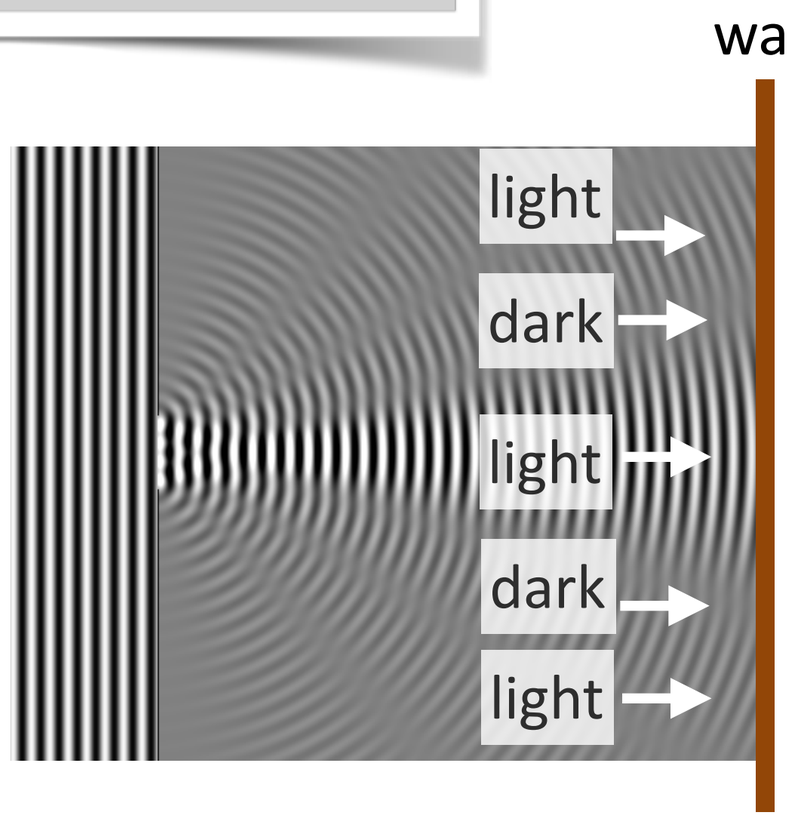
with light

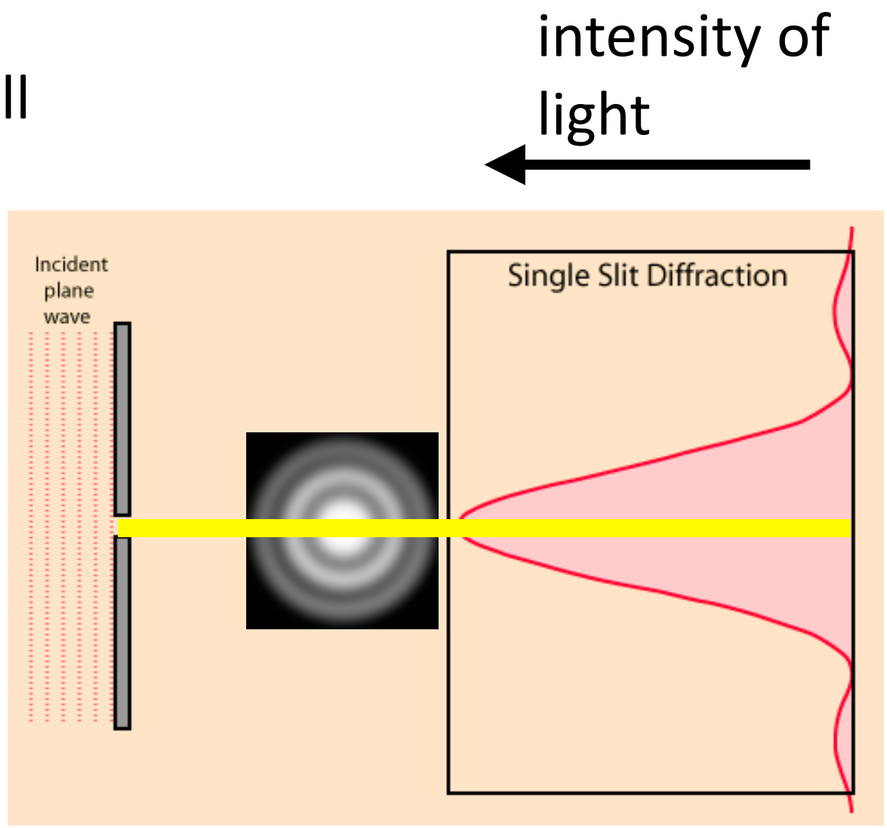
like that of water

wave height like brightness

crest: bright

trough: dark





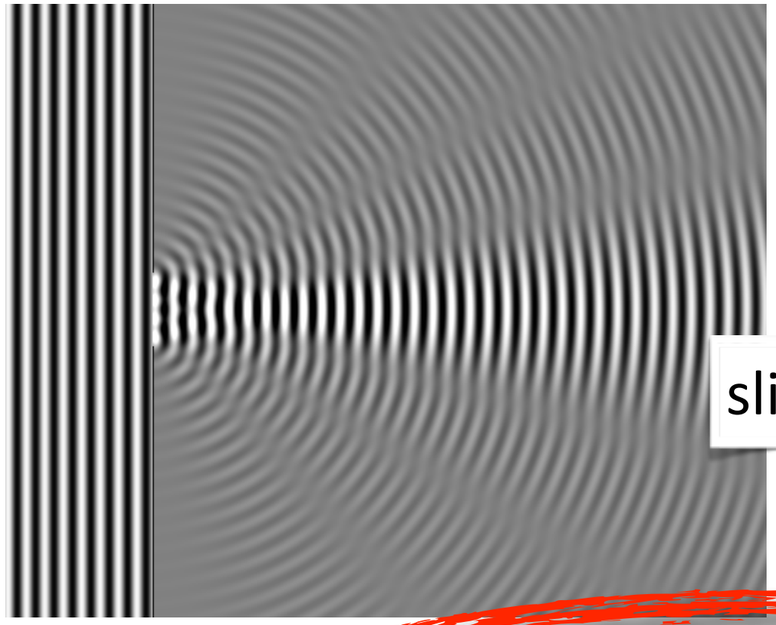
all across the width of the gap is light on the projected wall

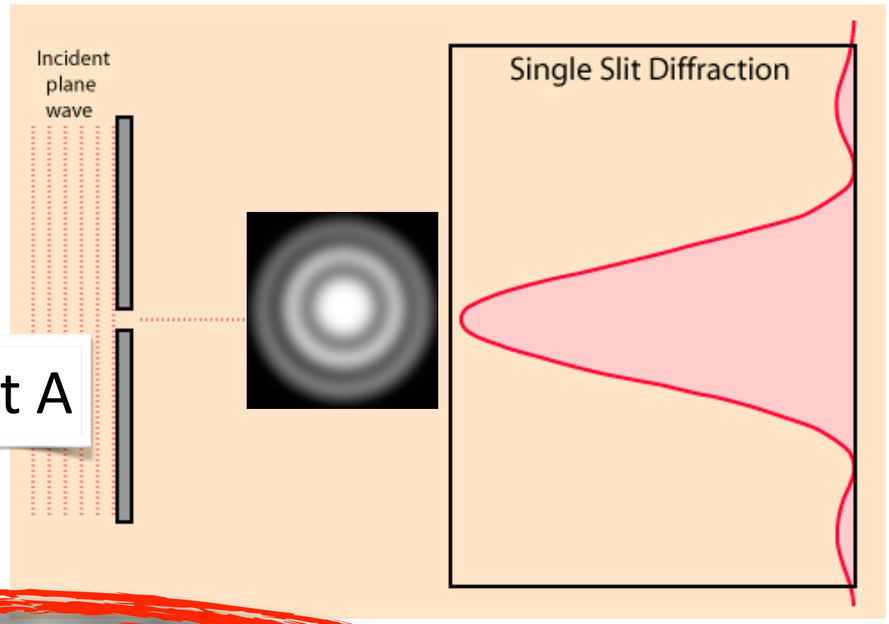
now do something strange.

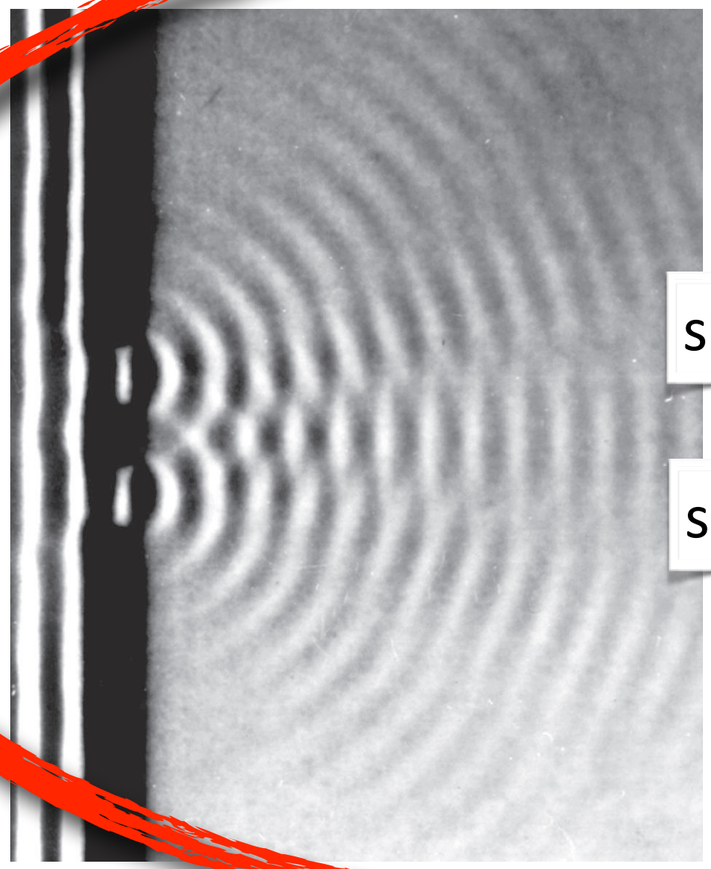
add light by opening another gap

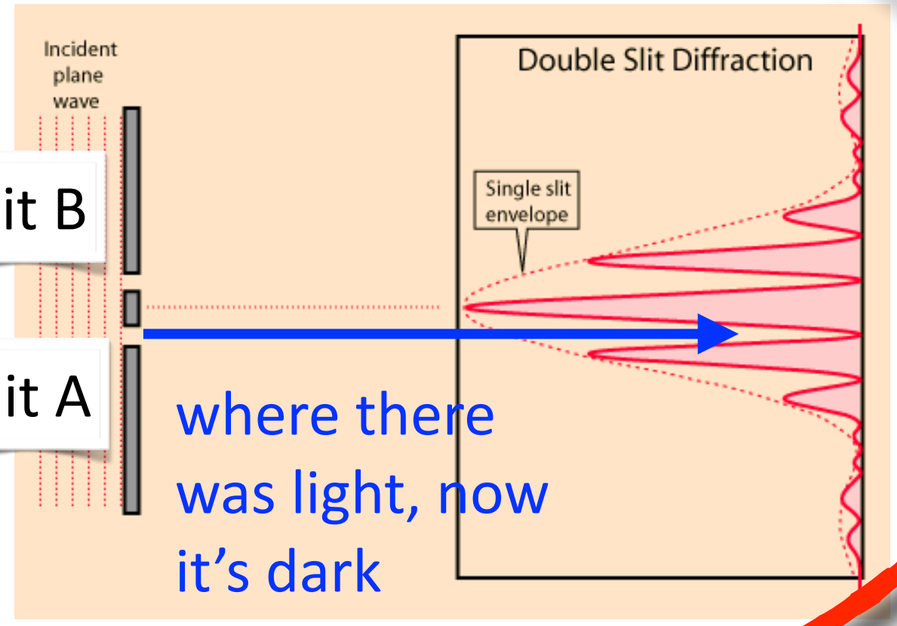
interference of light

and diffraction at the same time







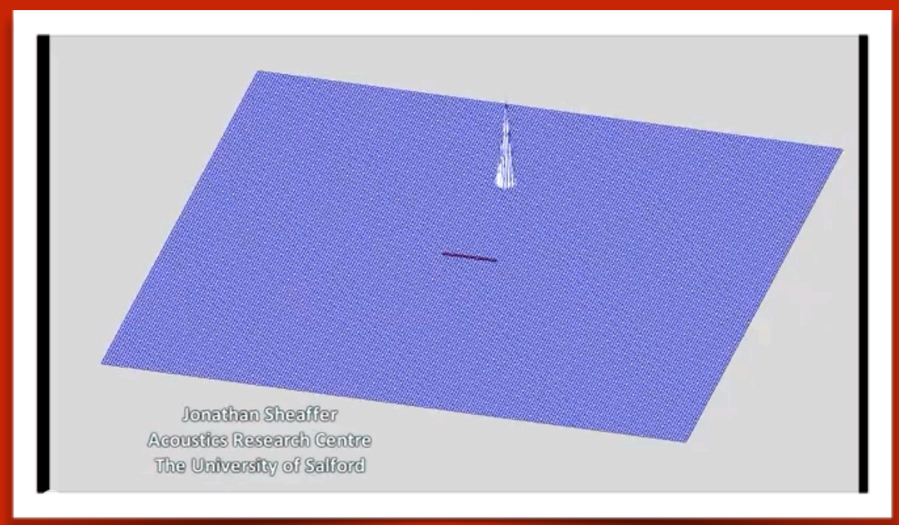


bottom line:

waves interfere…and they bend - they creep around edges

that’s diffraction

particles don’t do this!



yet, Einstein suggested that waves and particles are spookily connected together in one object - a particle of light

how’s that work?

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:

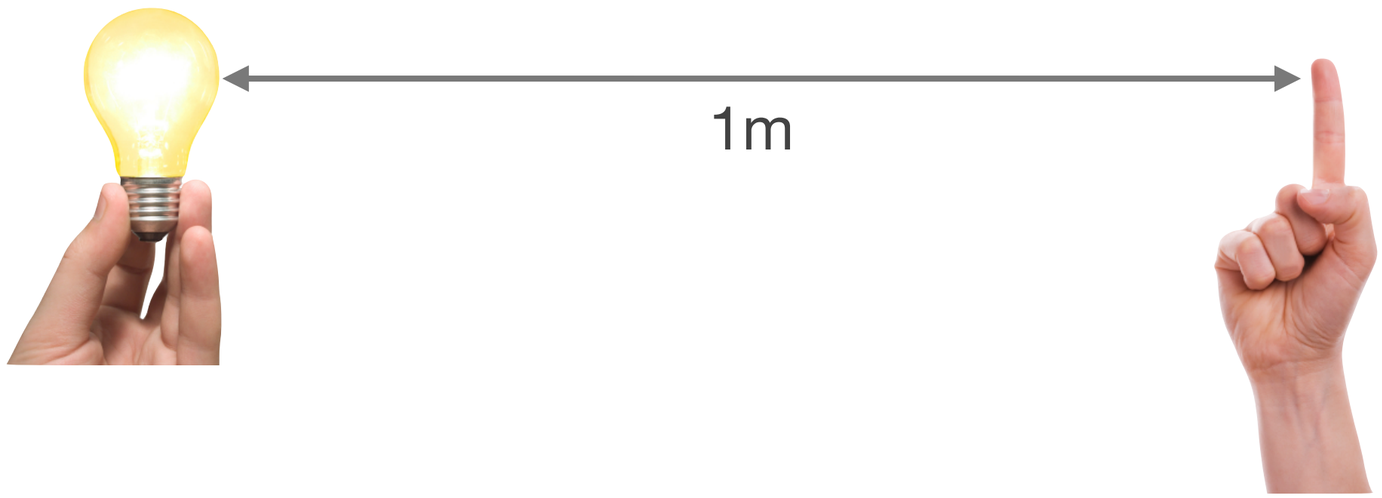
$$\text{Intensity} \propto Nhf$$

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

intensity, or power

number of photons

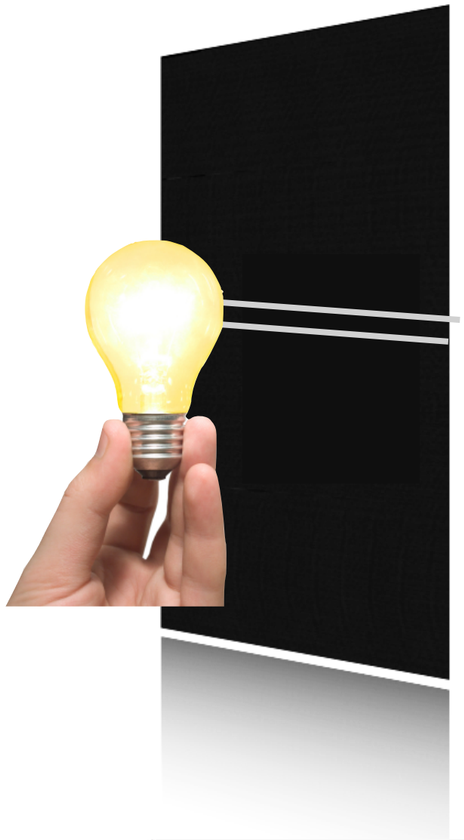
~10^{15} γ/s



here's how it works

let light go through a double slit

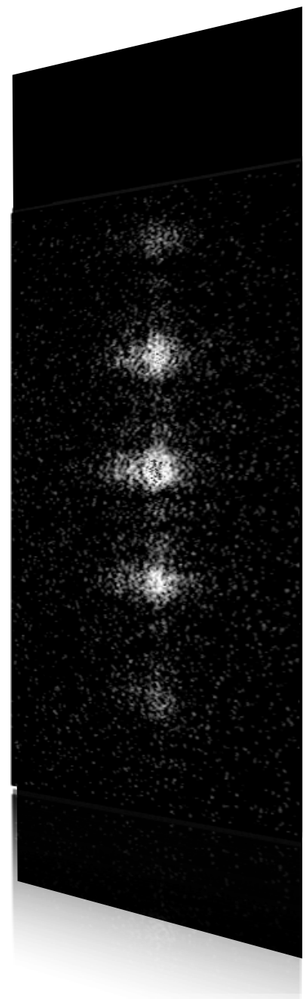
but sensitively count individual photons

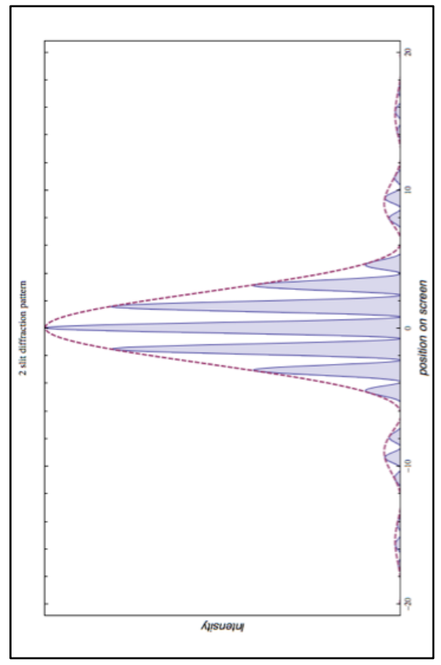


individual light particles

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.

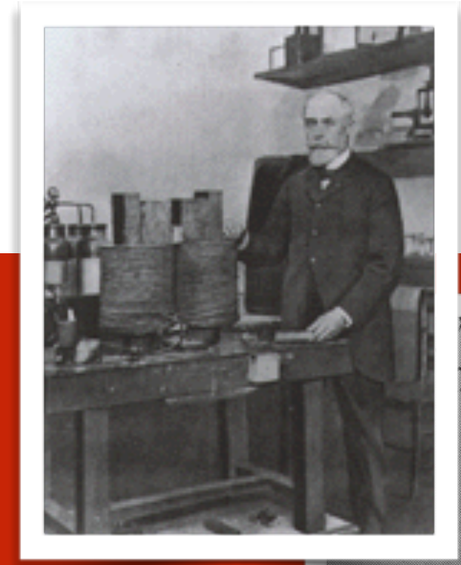
light behaves like a wave
and light behaves like a particle

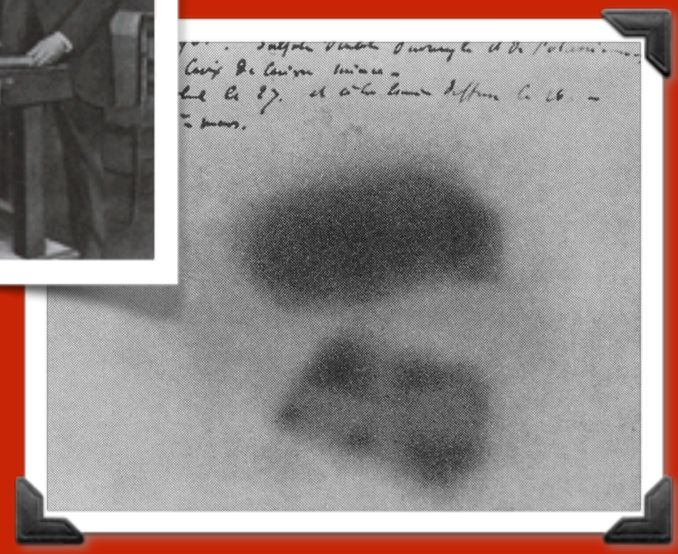
rewind a bit

to the beginning of Nuclear Physics

remember when we last saw the beginnings of radioactivity

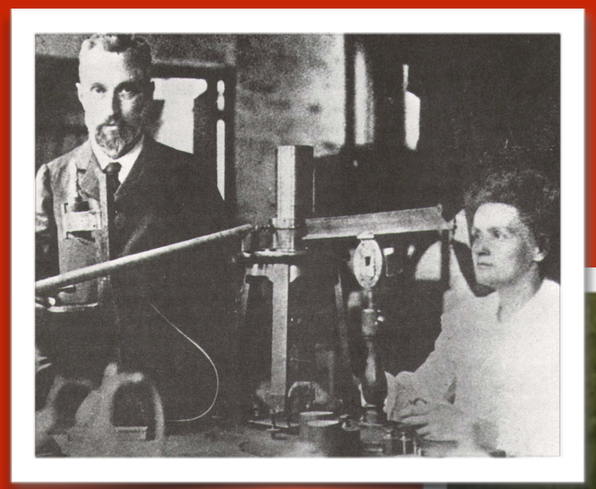
Becquerel’s adventures in cloudy Paris

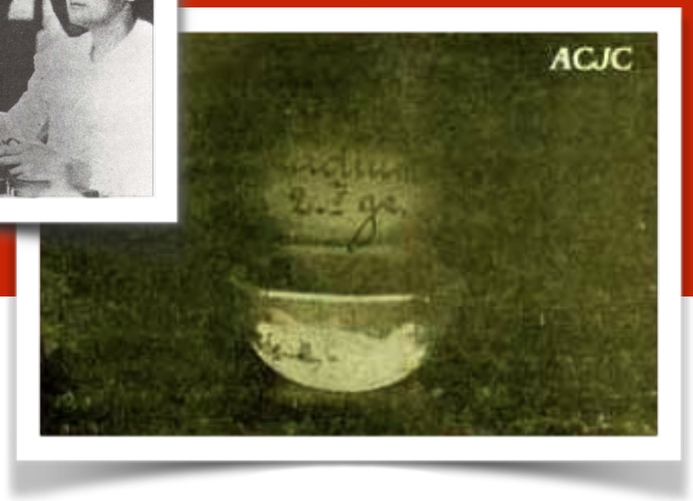


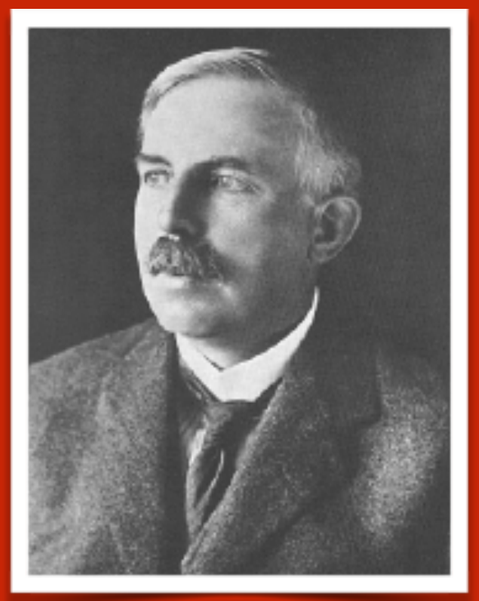


Marie and Pierre Curies’ isolation of Polonium and Radium

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







1899

Ernest Rutherford

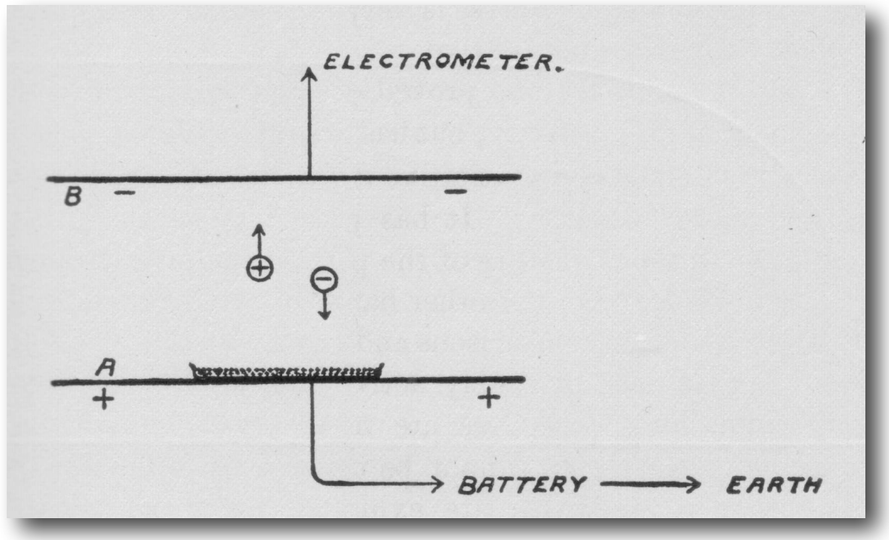
1871 – 1937

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

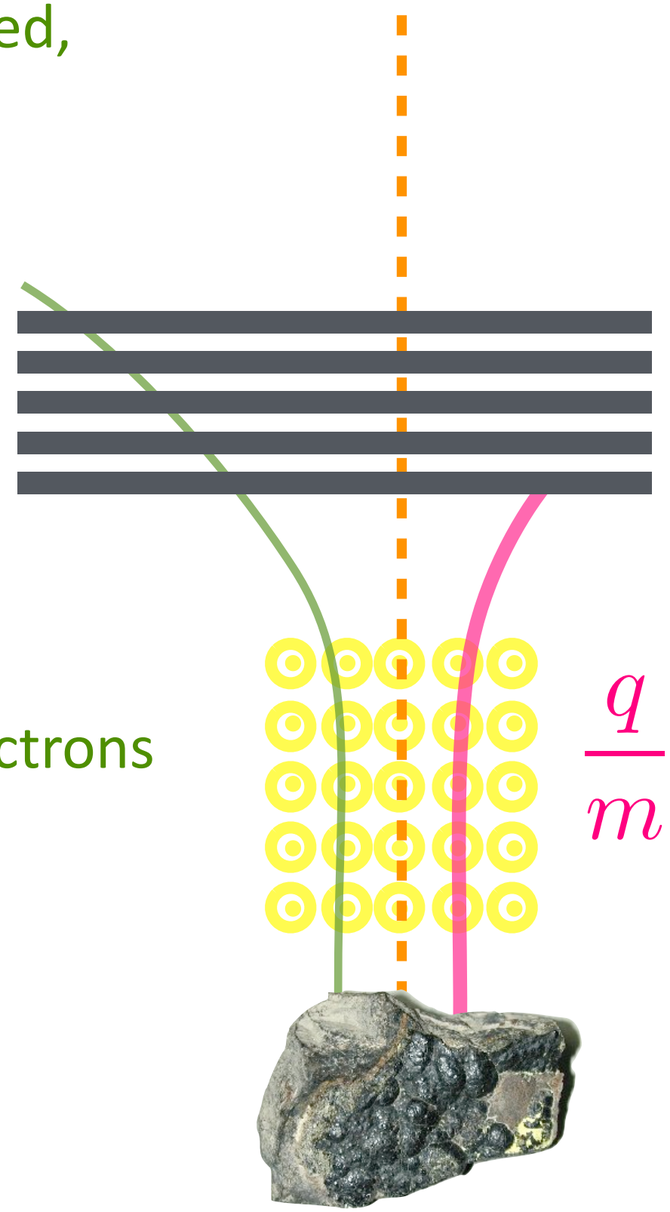
β

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

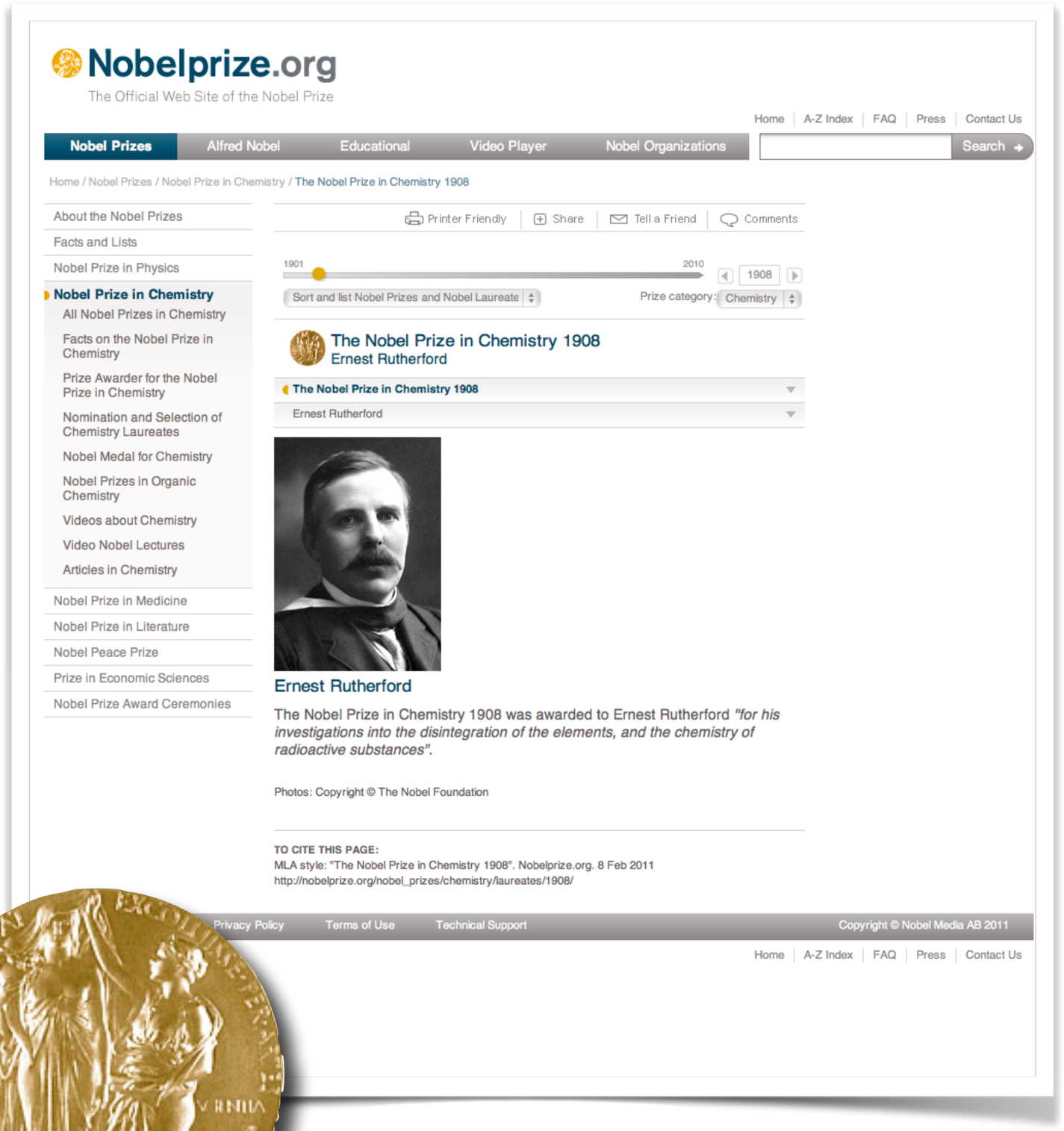
Nobel Prize in Chemistry

1908

which greatly amused him

and went on

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



finally, 1918

Planck got his due

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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.

TO CITE THIS PAGE:
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Max Planck, 1916

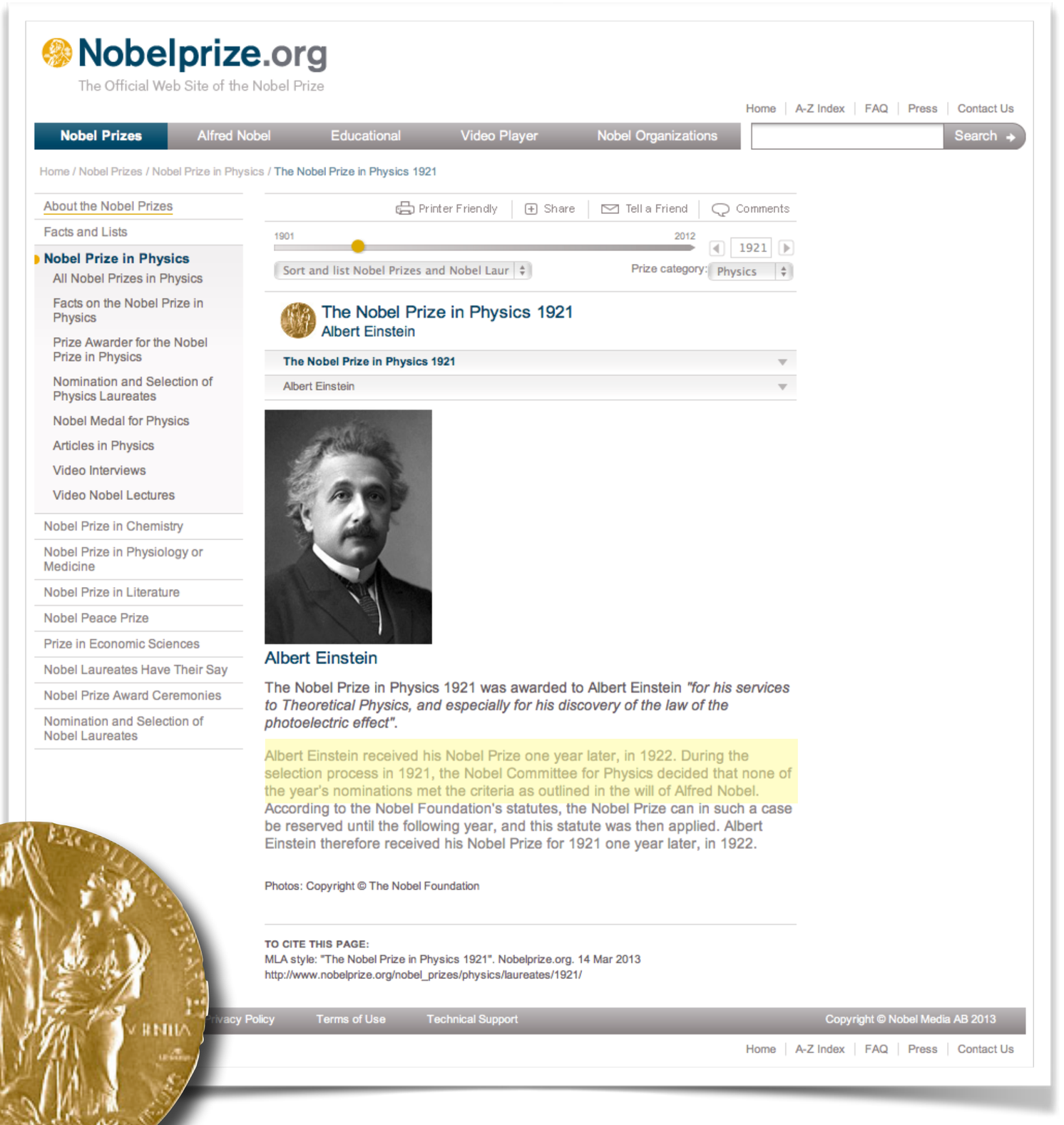
On nominating Einstein for membership in the Prussian Academy of Sciences:

“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*

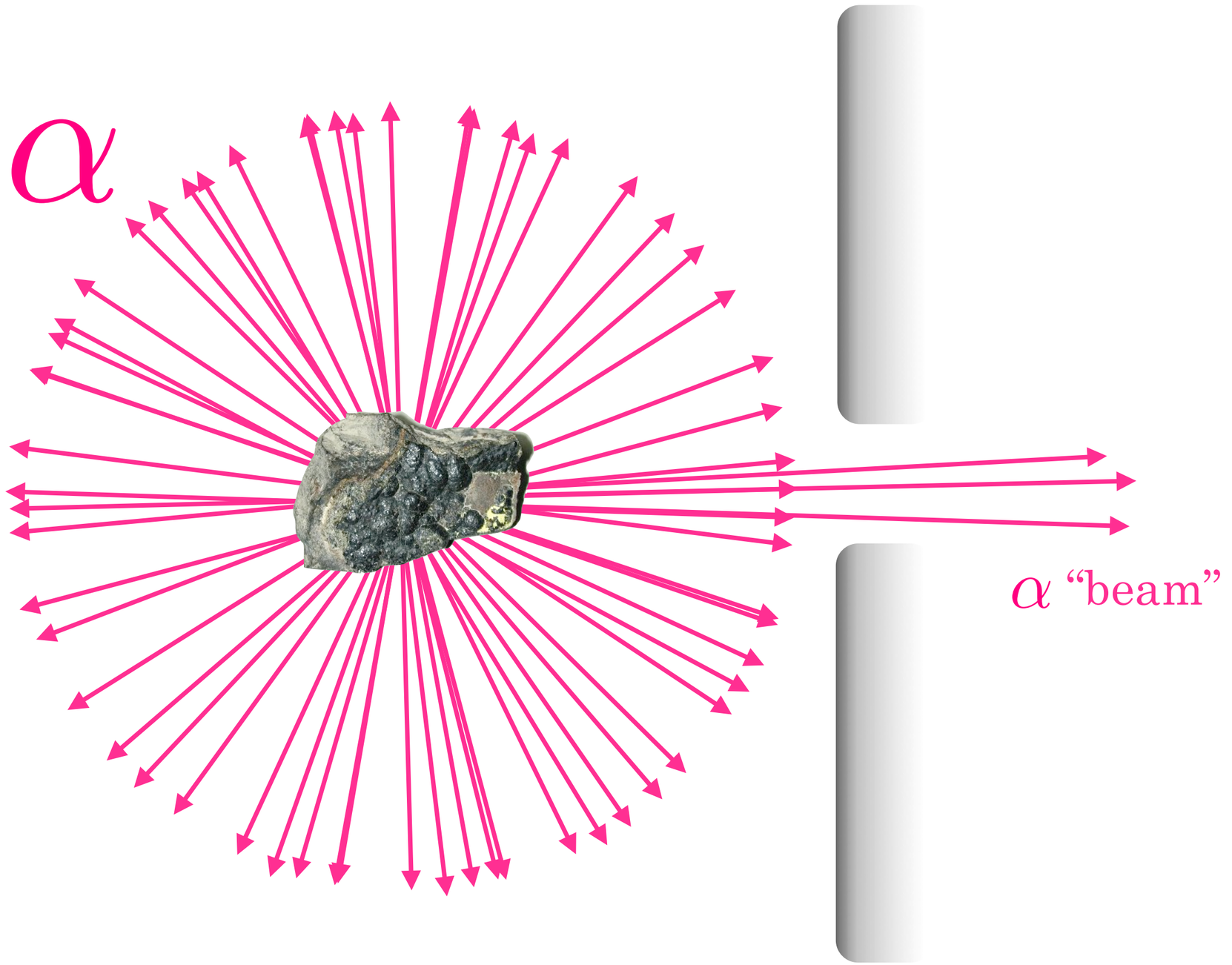
raisins: *specks of – electrons*

Rutherford went back to Britain

1907, Chair of Physics at University of Manchester

made "beams" of alpha particles using highly radioactive sources

Scattering experiments...



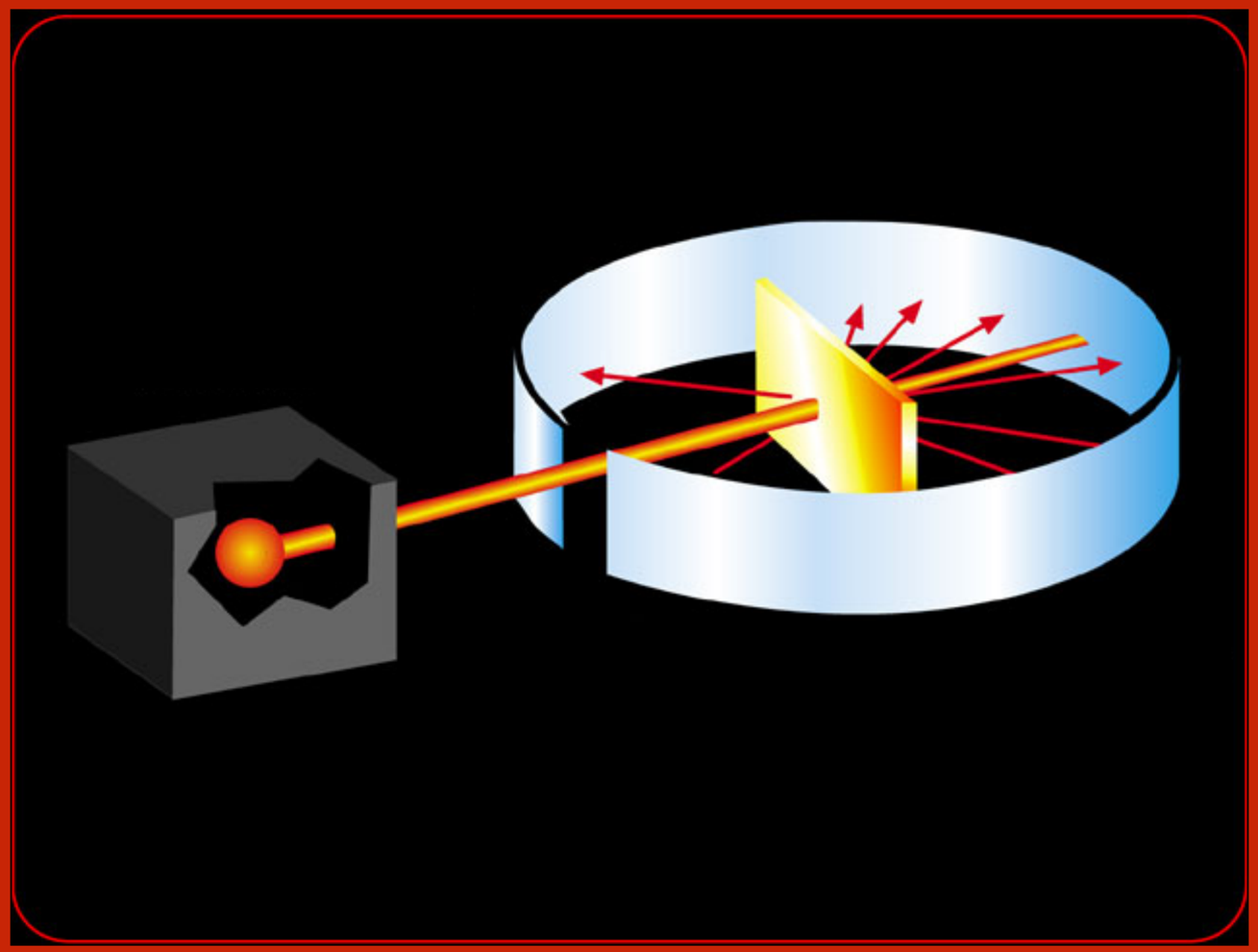
post doc

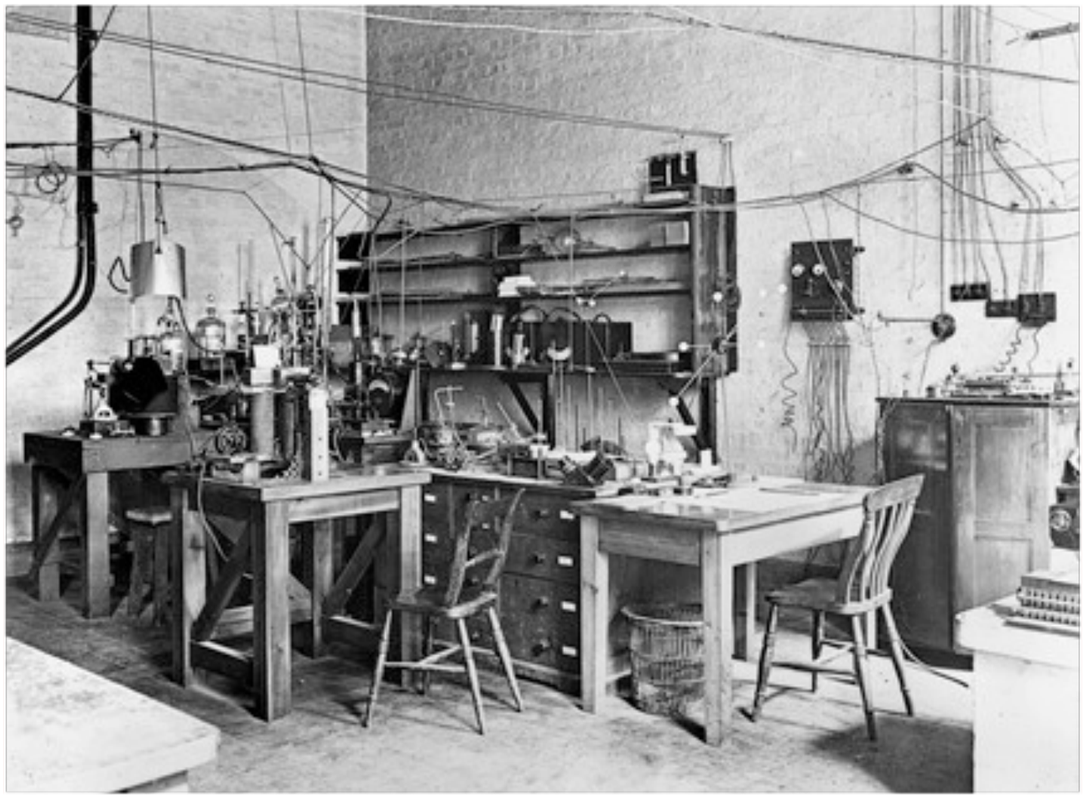
undergraduate student

Hans Geiger and Eugene Marsden studied

“scintillating” sheet

α particle scattering from Gold 1909






© University of Manchester

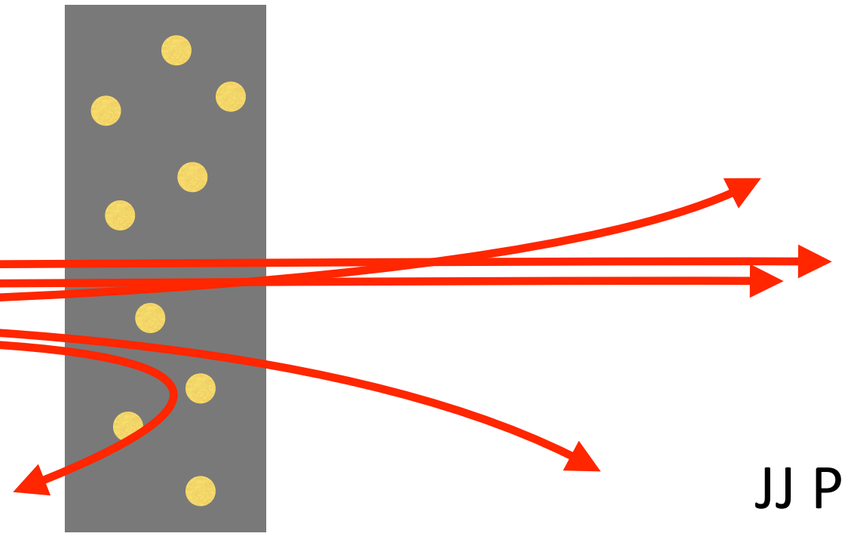
“It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back at you.

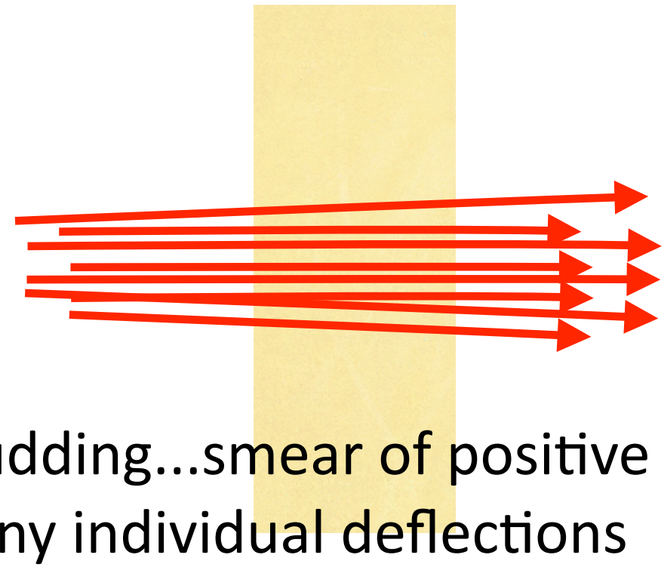
He had the solution after 2 years of work

he found:

1911: that the Atomic Number was +Ze

and made a model of the atom...





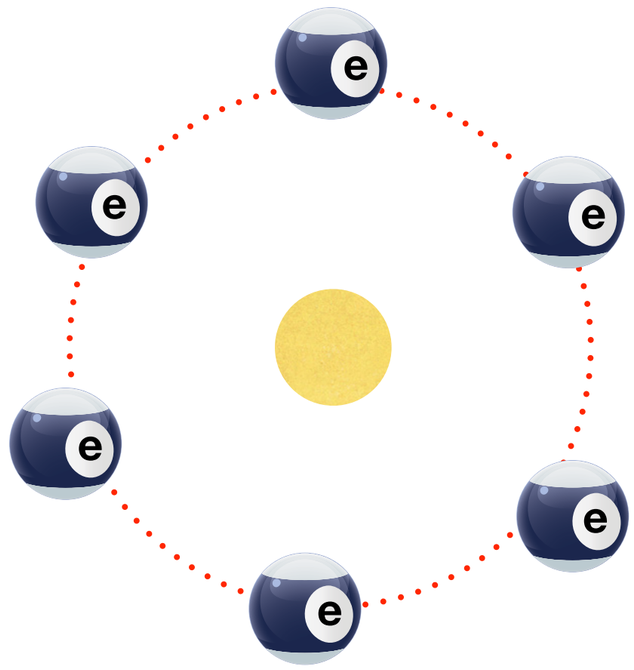
JJ Plum pudding...smear of positive charge - tiny individual deflections

the Rutherford Model of the atom:

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

The nucleus is tiny: most alphas go right through… only direct “hits” recoil.

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

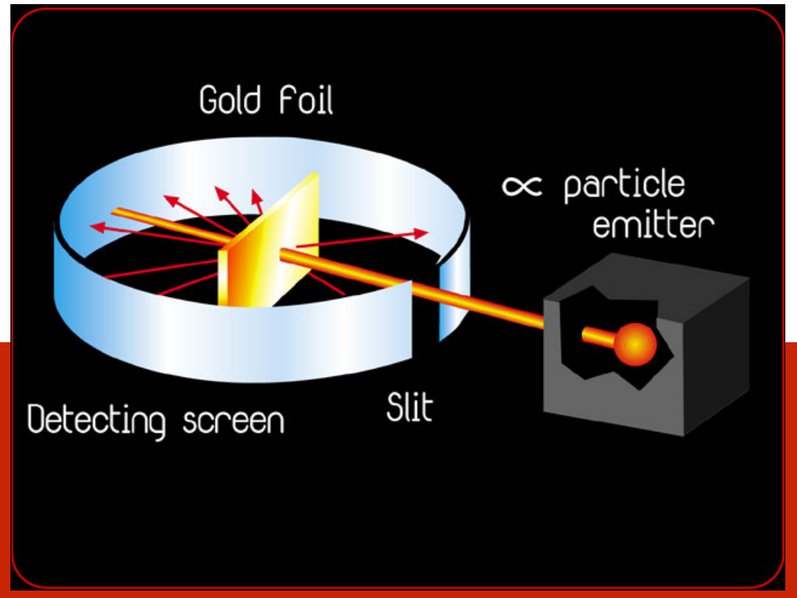


That’s problematic, the electrons would

accelerate...and

radiate.

a “spiral of death”

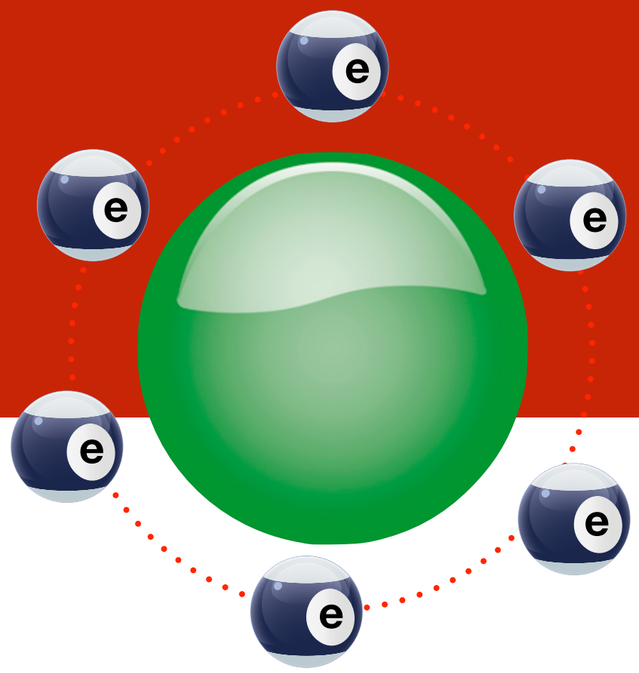


Measuring how often alphas scattered into different directions allowed Rutherford to estimate the size of the nucleus

the minimum size of the nucleus is

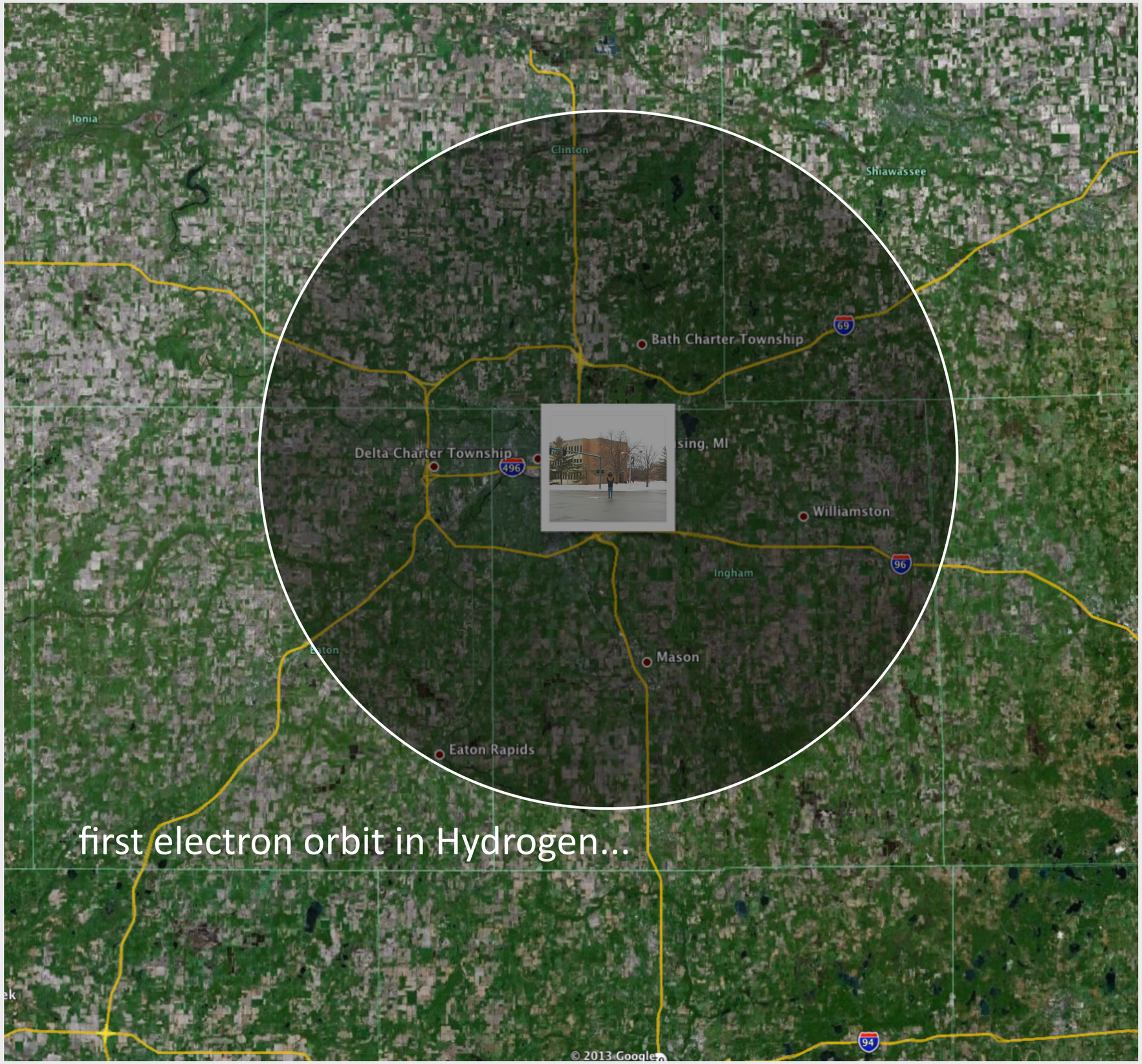
3×10^{-14} m

atom mostly nothing!

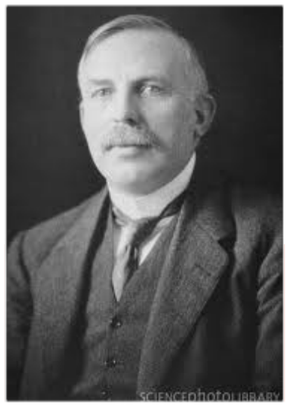


1 meter diameter ball

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

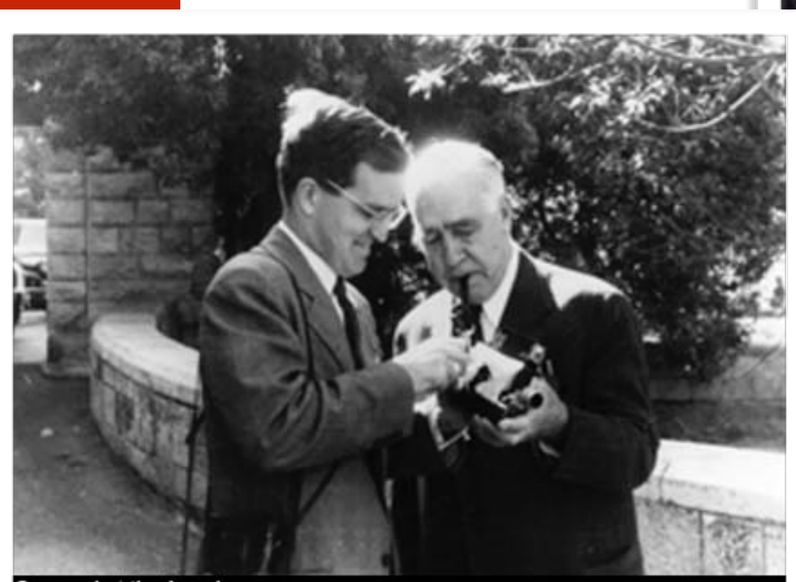
1913

Niels Bohr

1885 – 1962

a talker.

> Every great and deep difficulty bears in itself its own solution. It forces us to change our thinking in order to find it.
>
> How wonderful that we have met with a paradox. Now we have some hope of making progress.
>
> When it comes to atoms, language can be used only as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images.
>
> It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we say about Nature.



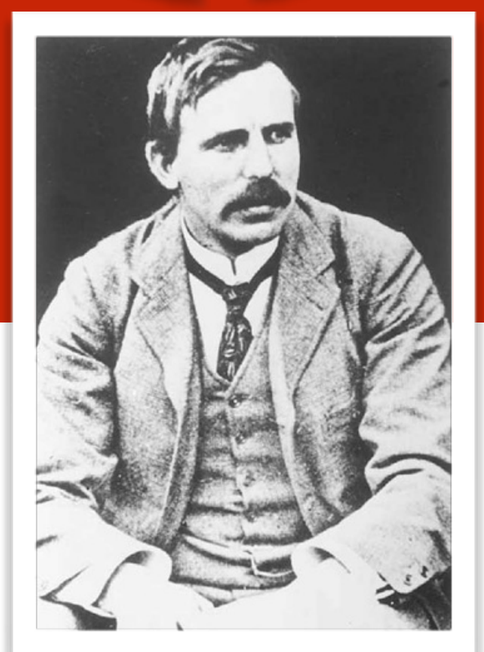
Rutherford not disposed kindly

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

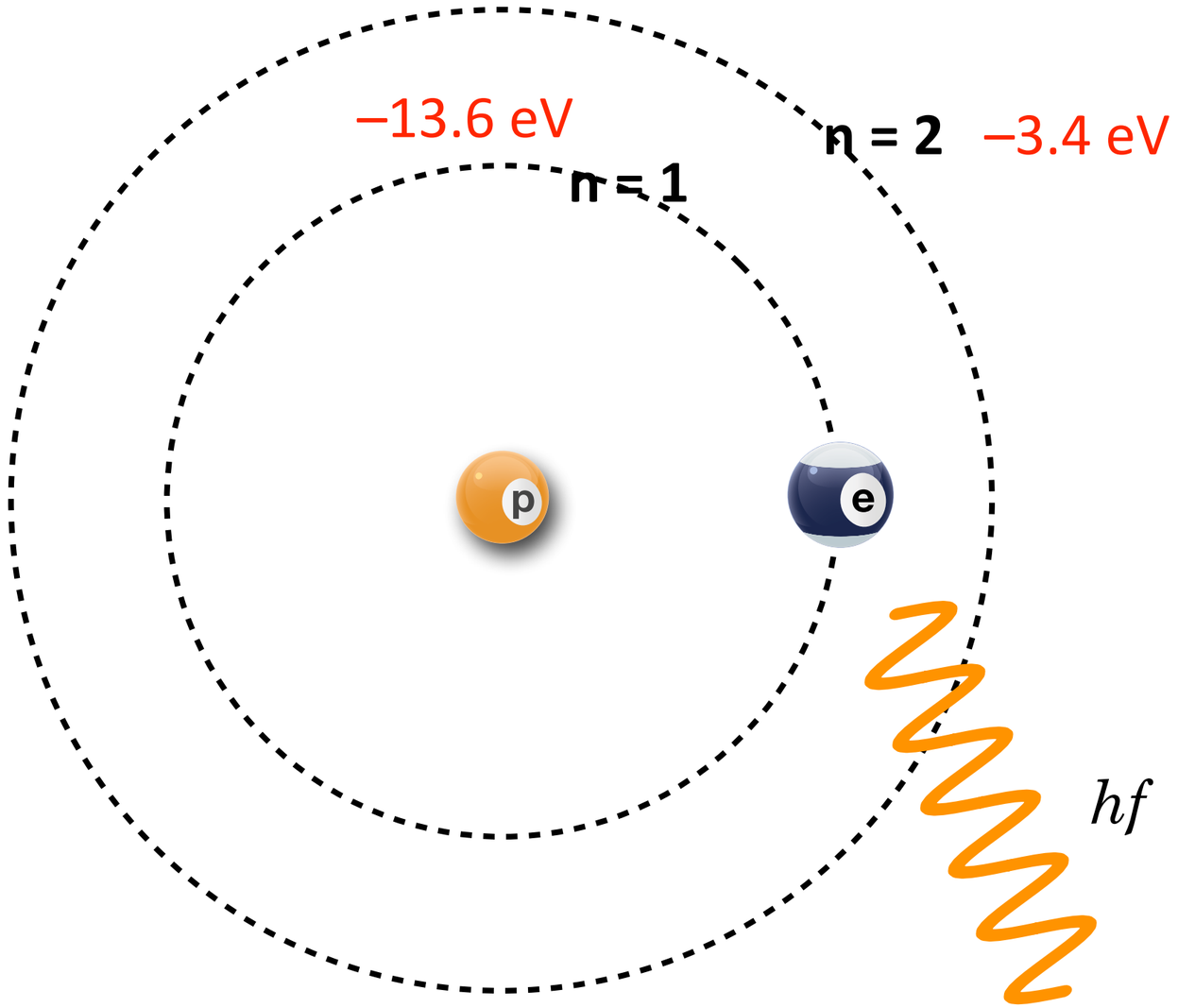
That at atomic distances...

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

fixed “quantized” orbital radii and orbital velocities

the magic of Bohr's model:

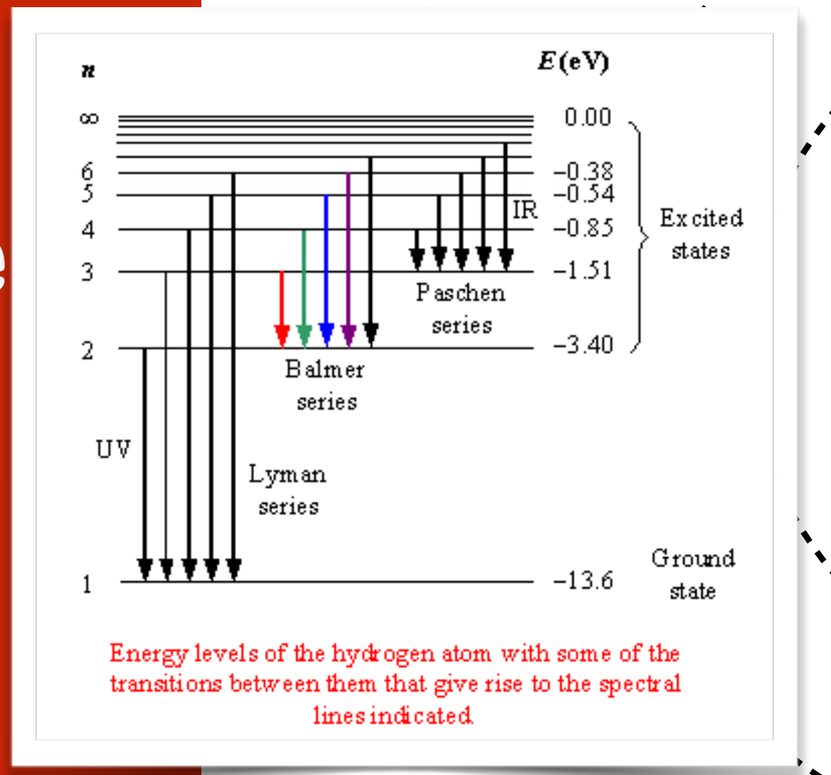
the idea of an atomic transition



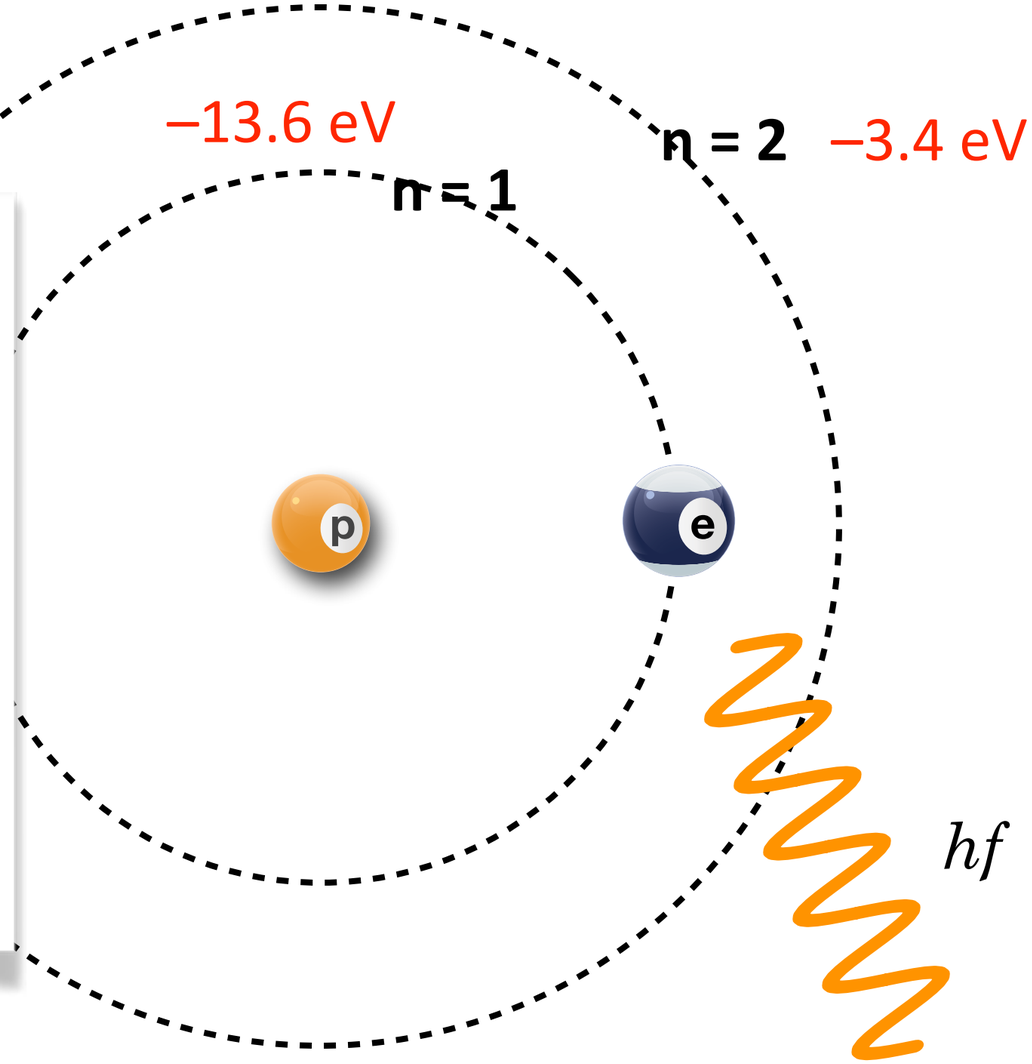
The idea: transition of electrons results in the released energy of a photon...of a particular energy

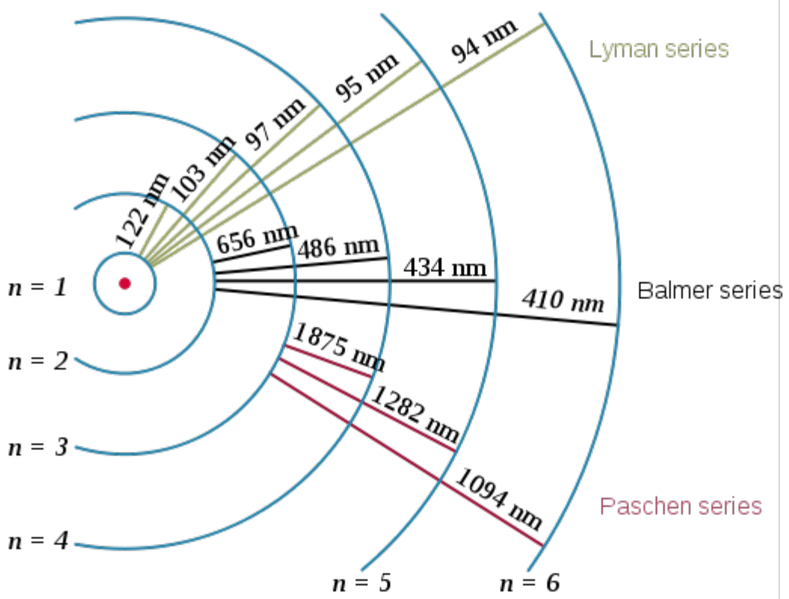
imagine his surprise

1913: his way.



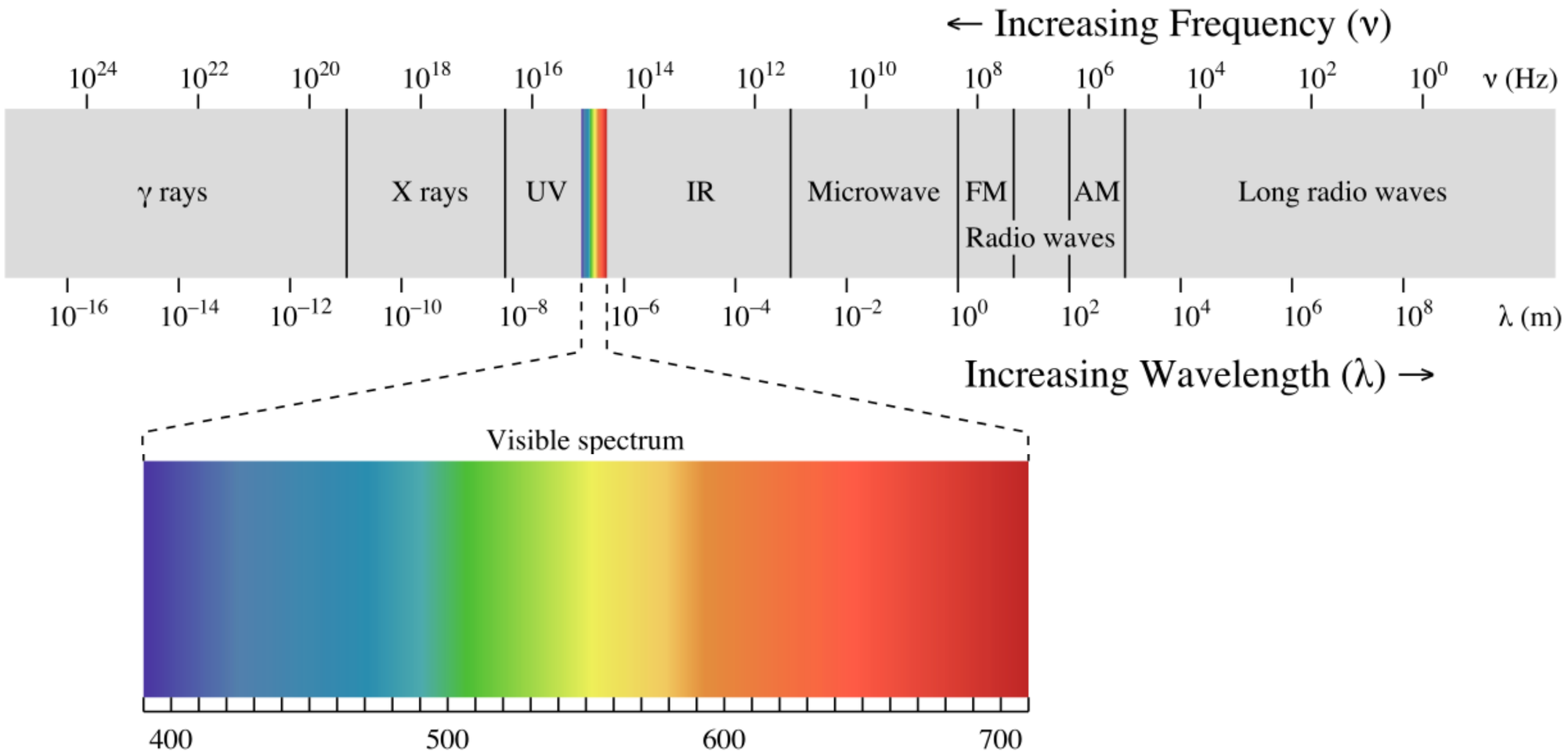
Energy levels of the hydrogen atom with some of the transitions between them that give rise to the spectral lines indicated.





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

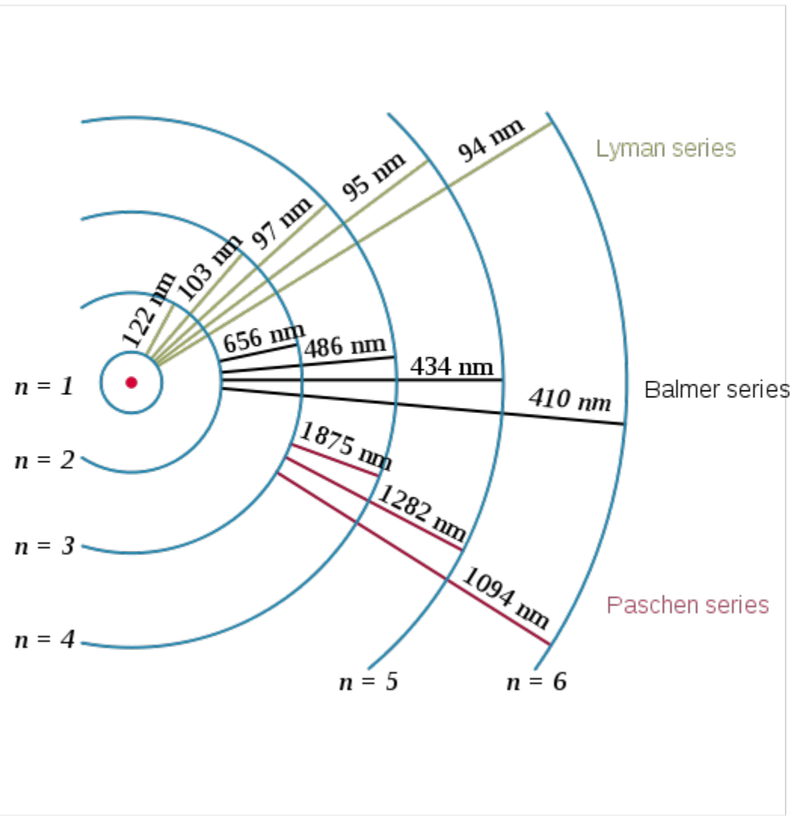
$$E_2 - E_1 = 10.1\ \text{eV} \longrightarrow \lambda = 122\ \text{nm}$$



410 434 486 656

nm

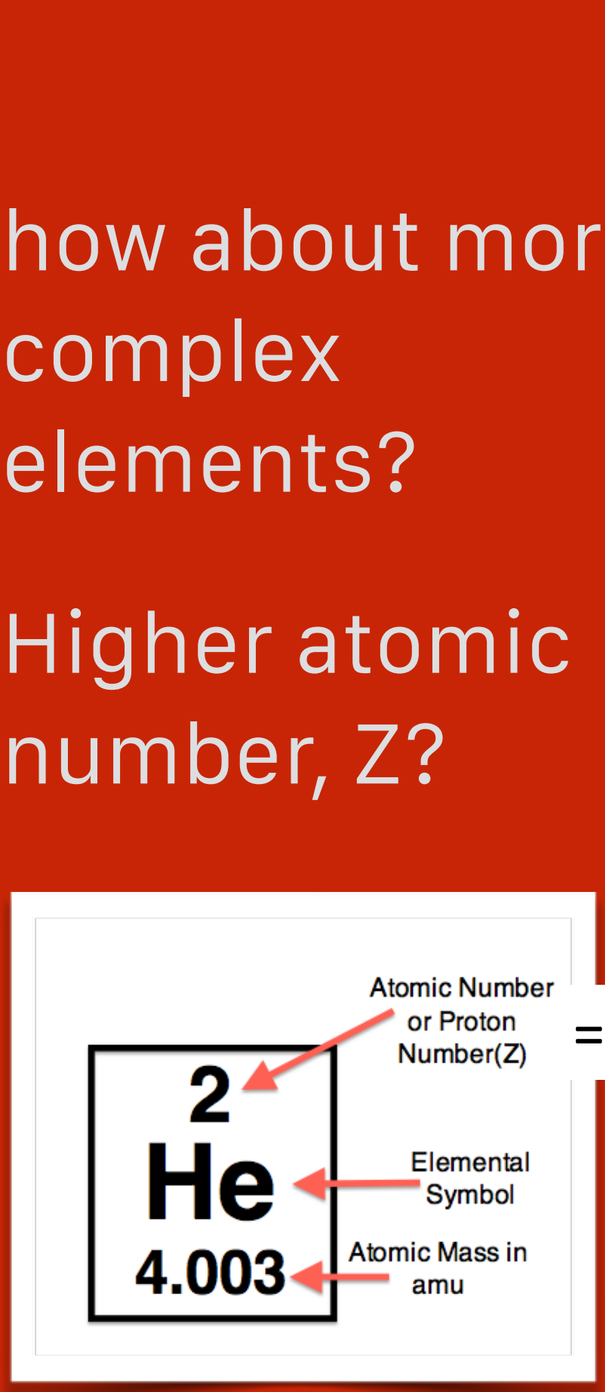
Hδ Hγ Hβ Hα



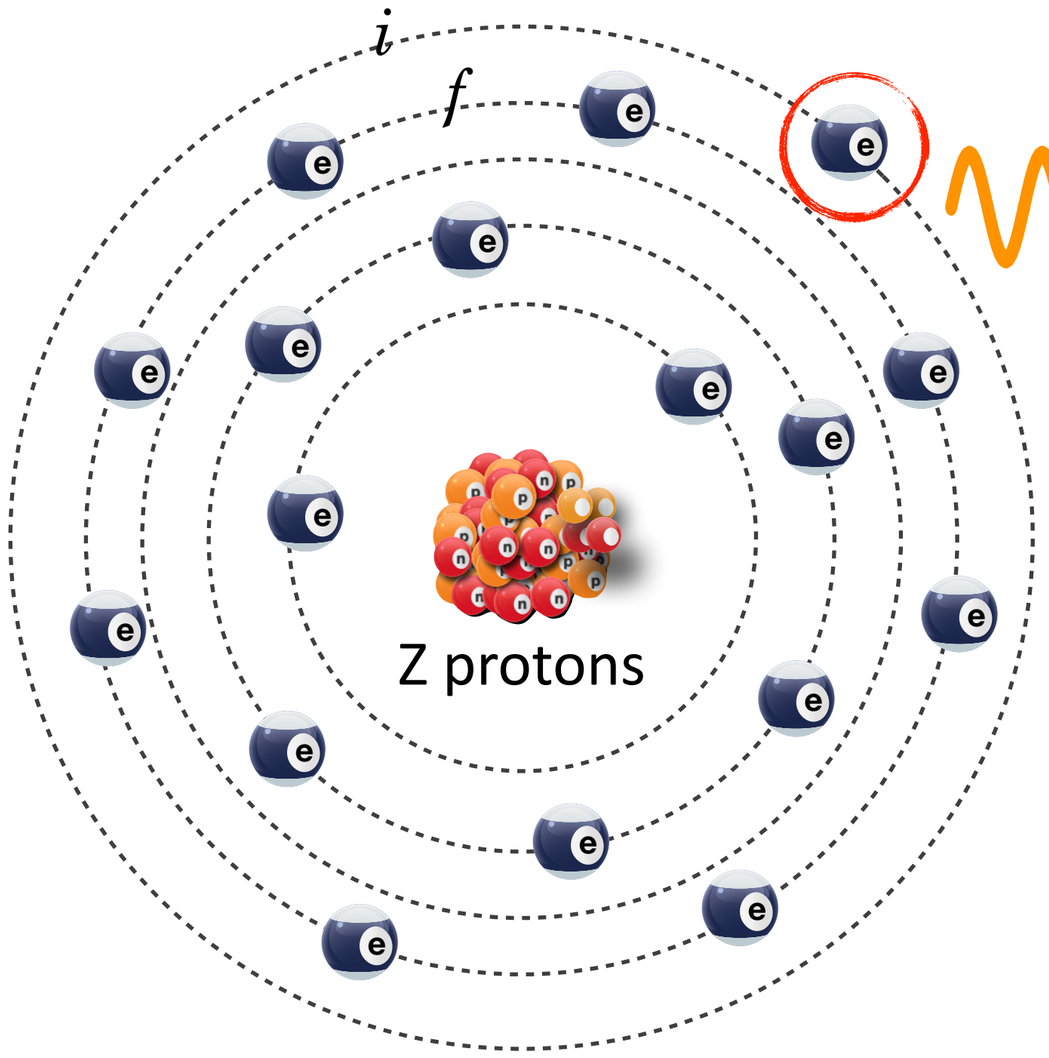
hydrogen, fine

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....

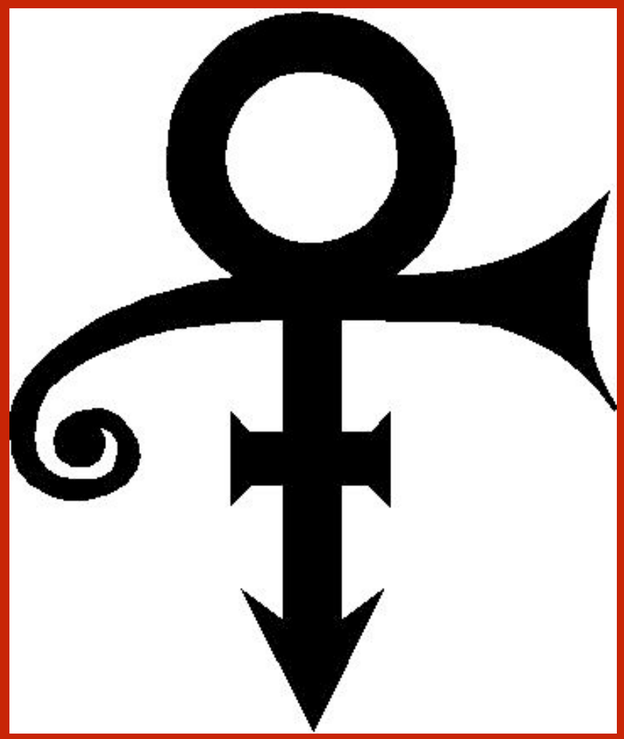
yup, 1922

actually with Einstein's delayed prize

then

it got strange

quantum idea of electrons



Prince Louis de Broglie

His 1922 PhD thesis:

"The French Comedy"

must have been disconcerting

The Prince looking self-satisfied

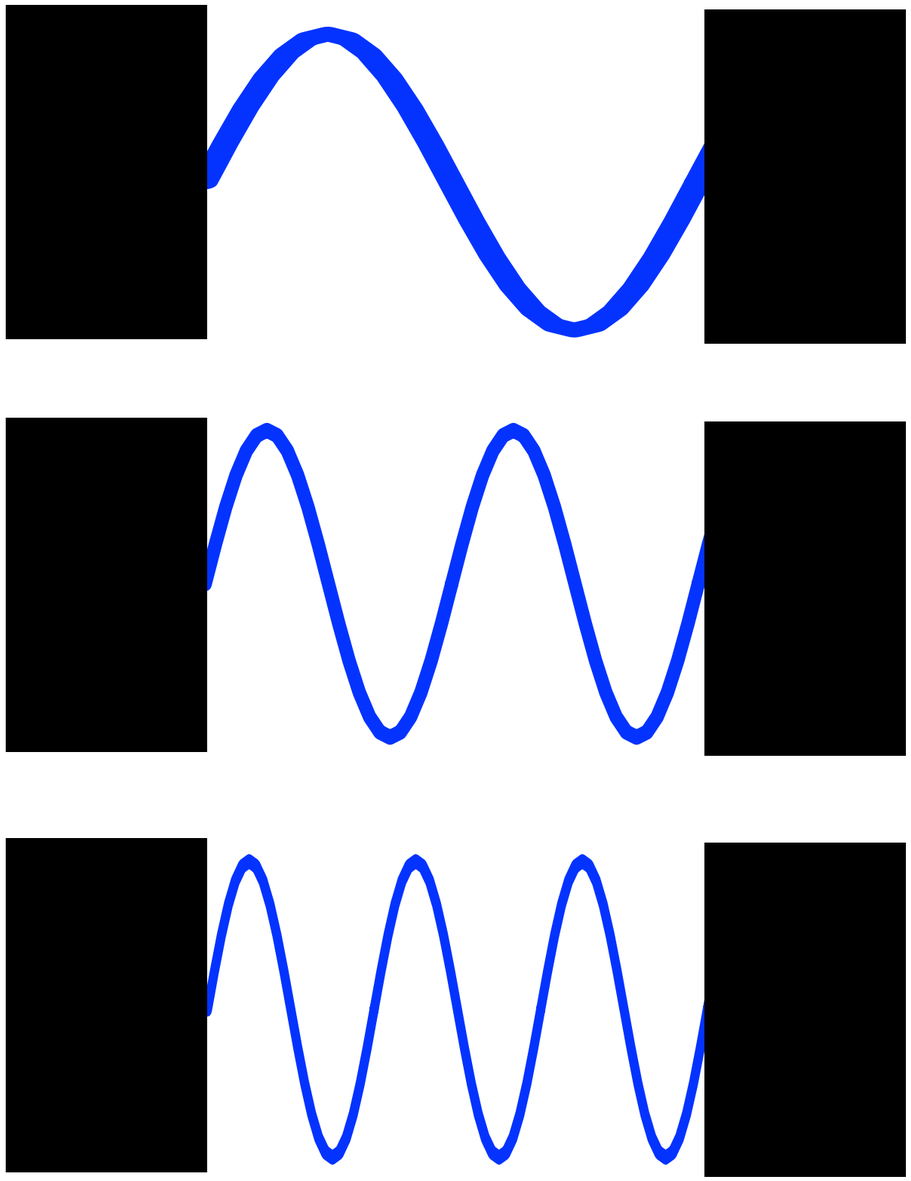
the quantum idea:

made use of **integers**

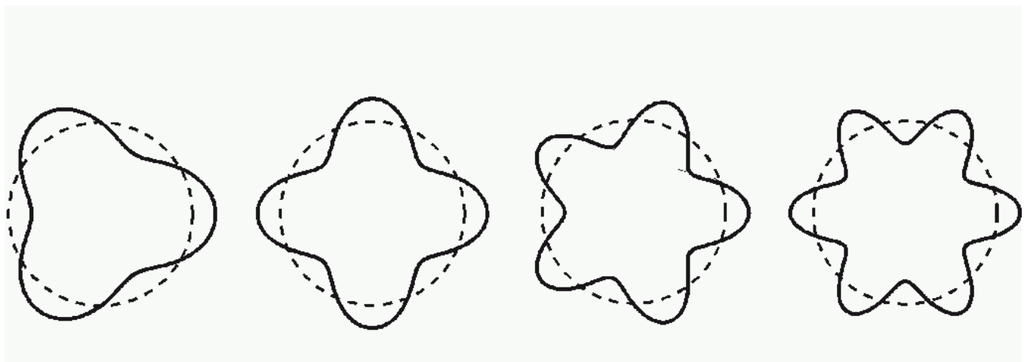
so do waves

a standing wave

uses integers

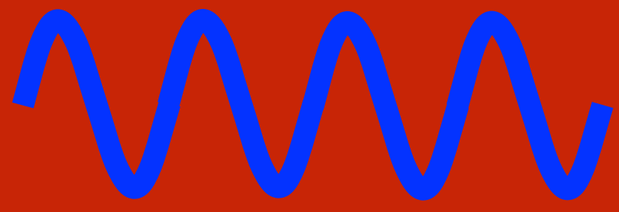


Suppose the integer's in Bohr's formula...had to do with standing waves? Wrapped around a circle?



But...you sputter...I thought the orbits were electrons?

A standing wave, wrapped around in a circle



Following Bohr:

photons

undeniably wave and particle-like

in atoms they involve integers directly.

hmmm, thought the Prince

One other thing involves integers

standing waves

well

go from photons to matter...!

Remember the total energy relation?

$$E_T^2 = (mc^2)^2 + (pc)^2$$

In which objects with m = 0 have energy:

$$E = pc$$

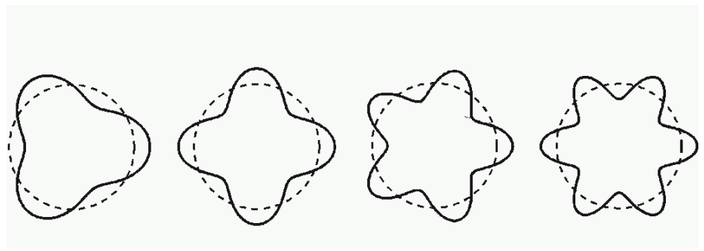
rearrange... $$p = \frac{E}{c}$$

use the Planck relation for E:

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$

Pretend that this Photon-inspired, standing wave idea **works for electrons of momentum p.**

Electrons with a wavelength!



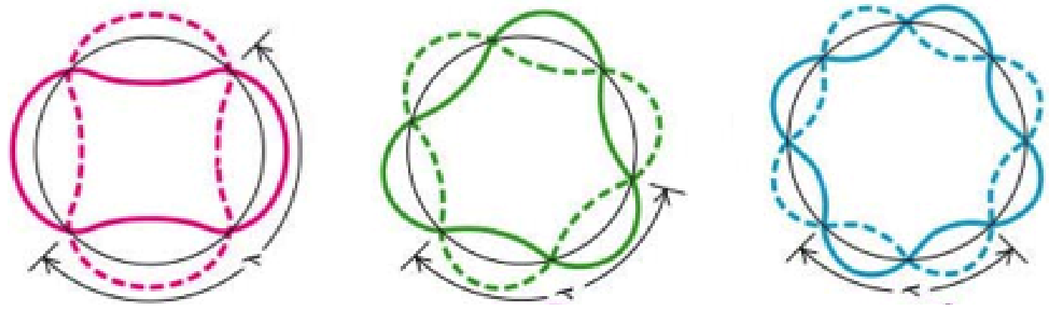
the momentum of an electron

related to the wavelength of an electron

the wavelength of an electron??

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$

now, a relation for an electron!



n = 2 3 4

deBroglie guessed that the Bohr quantum number was related to the number of standing waves of the electron around the nucleus

photons:

$$\lambda_\gamma = \frac{h}{p_\gamma}$$

electrons:

$$\lambda_e = \frac{h}{p_e}$$

$$\lambda_e = \frac{h}{m_e v}$$

that was deBroglie's hypothesis

electrons are particles and waves

his PhD examination committee was so scandalized

they actually asked Einstein for advice

Who said: "sounds good to me."

this relation will be important

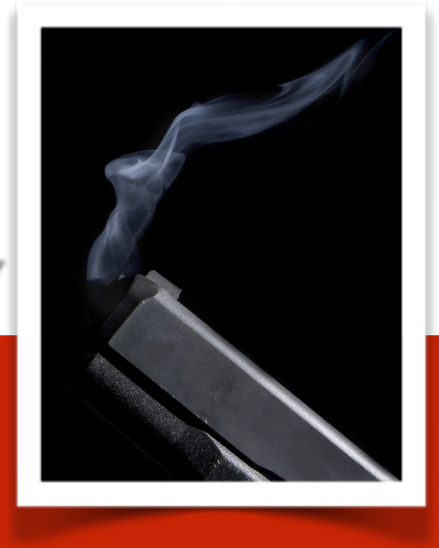
relating the wavelength of a quantum object

to its momentum

“deBroglie relation”

$$\lambda = \frac{h}{p}$$

particles as waves?

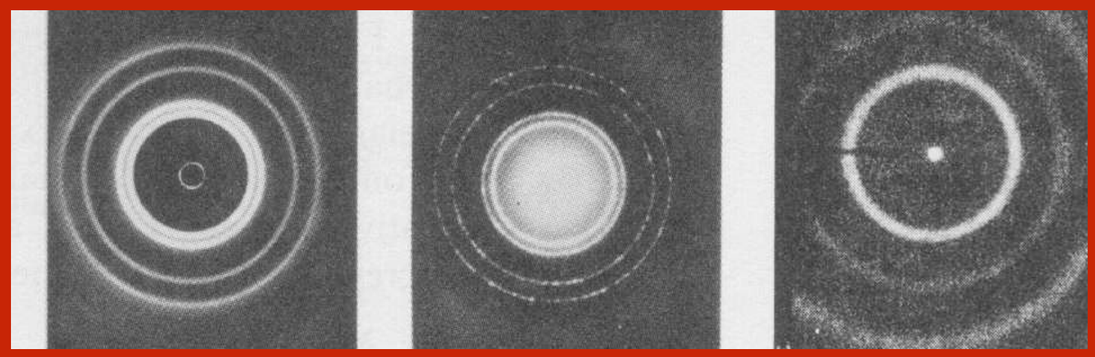


deBroglie suggested how:

they should exhibit diffraction

1927

Davisson & Germer

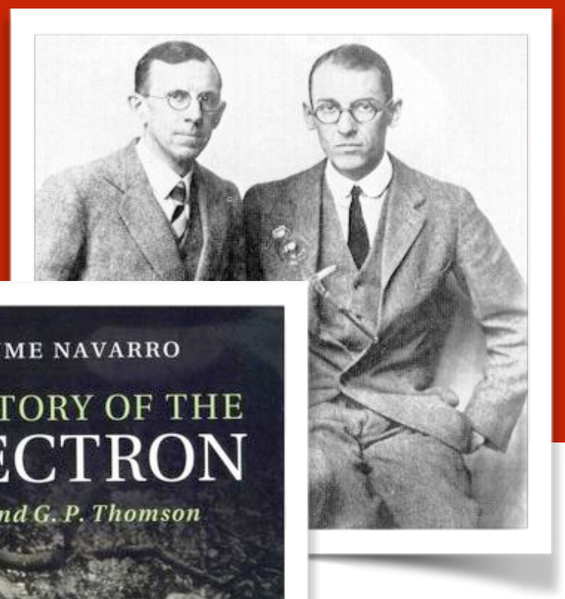


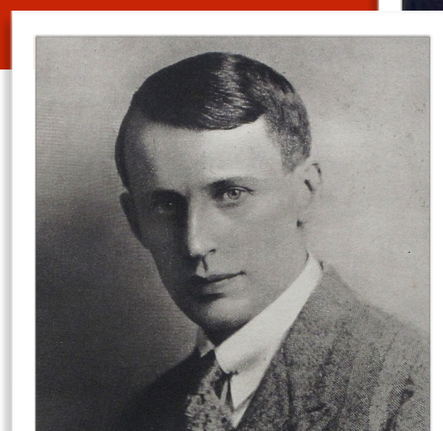
0.071nm X-ray diffraction on a polycrystal

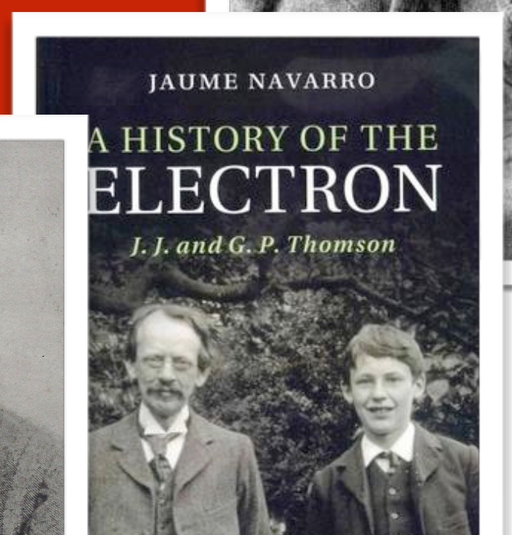
600 Ev electron diffraction on a polycrystal

0.057 ev neutron diffraction on a polycrystal

a “slit” appropriate for X-ray wavelengths







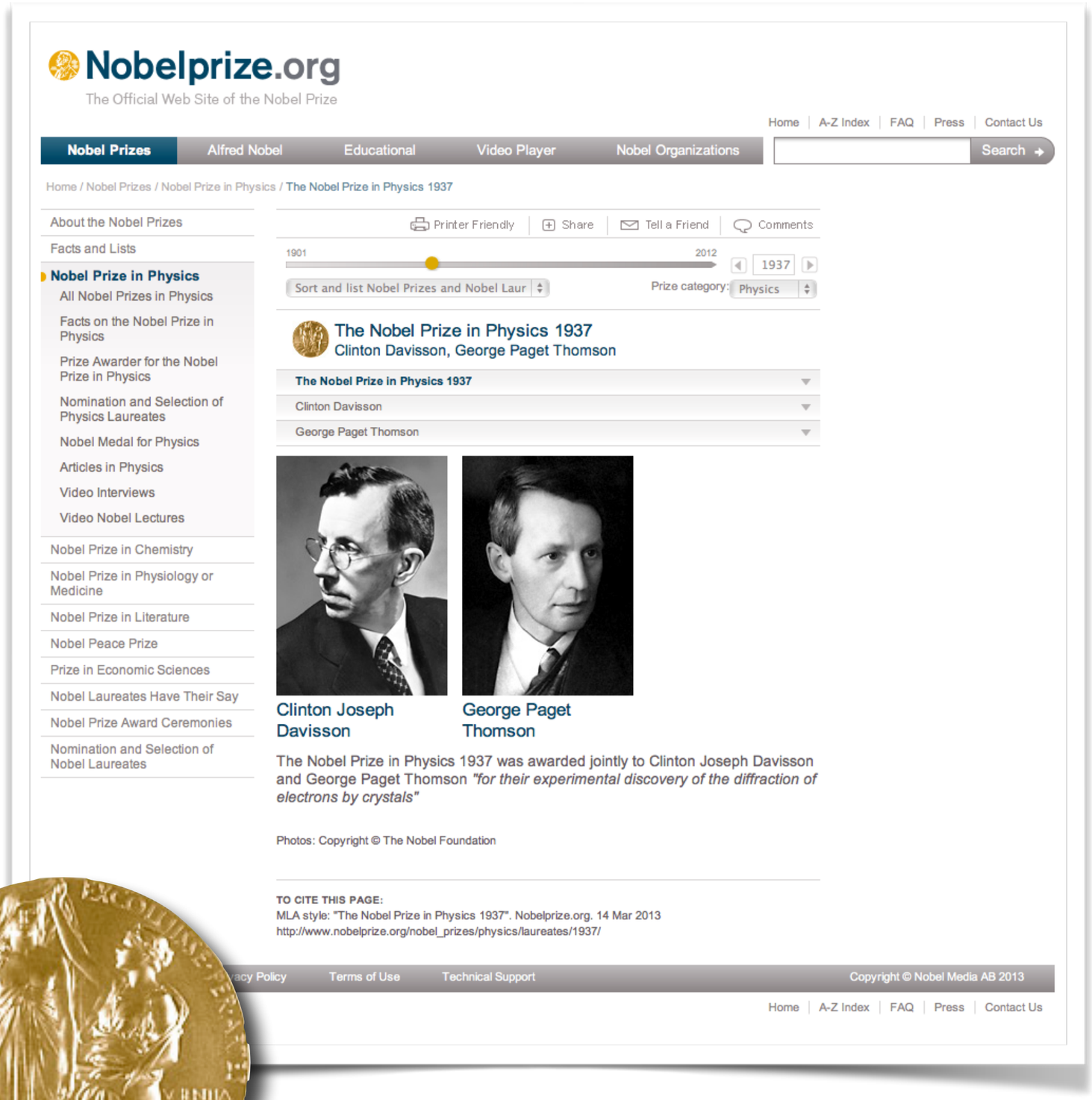
JJ's son GP

JJ got the Nobel for showing that the electron exists and is a particle

GP got the Nobel for showing that the electron is a wave

Germer lost out

Nobel rules: 3 people.



in one picture

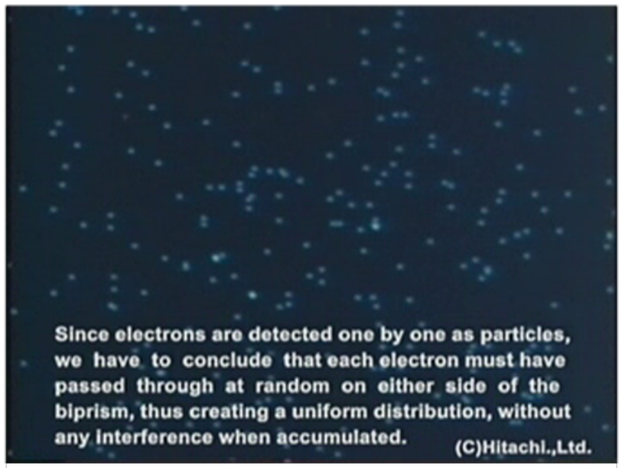
both the particle like features of electrons

the dots

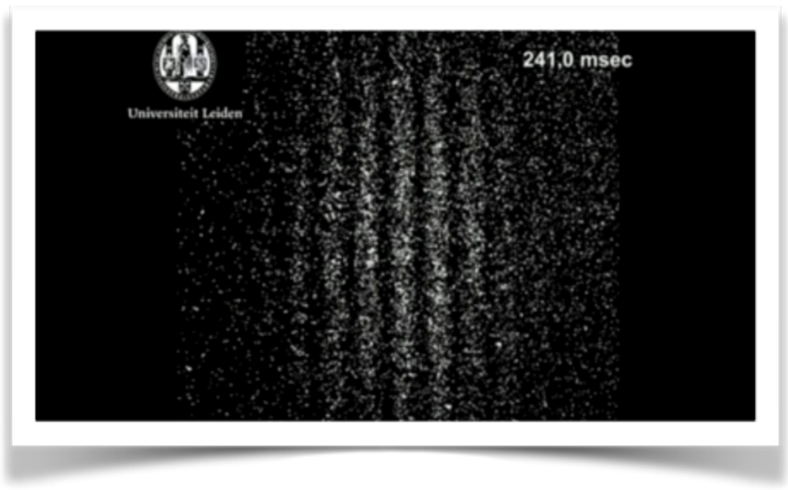
and the wavelike features of electrons

the diffraction pattern

http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm



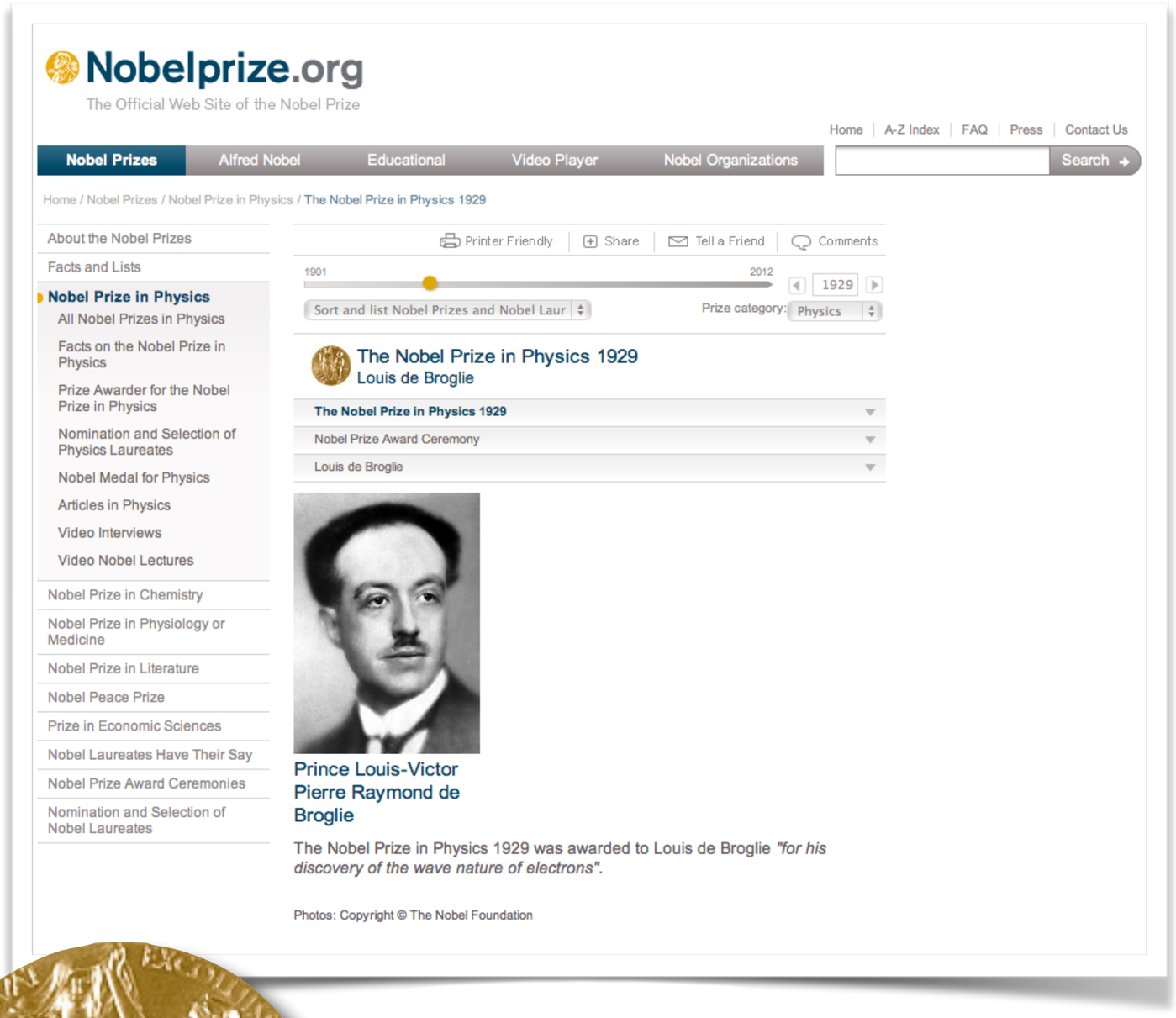
electrons!



photons!

sole winner

1929



get real

I weigh 200 lbs & I walk 5 mph

what's my wavelength?

$$p = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{mv} = 3 \times 10^{-36}\ \mathrm{m}$$

Smaller than the nucleus...My waviness doesn't show.

Why is it so small?

Two reasons:

1. My momentum is huge, downstairs
2. Planck's Constant is tiny

Quantum Mechanics born of some anxiety

the lack of radiation of Bohr's accelerating electrons was still a problem: Bohr knew it and figured there would be a more complete answer.

what in the world is an electron in deBroglie's scheme?

There was much that was ad hoc and not believable

both in Bohr's approach and deBroglie's

however, the experimental situation made it clear that the broad suppositions of both had to be a part of the truth.

Quantum Mechanics, proper was the child of 3+1 people:

Werner Heisenberg - 1925; invention #1

Erwin Schrödinger - 1926; invention #2

Paul Dirac - 1925; showed #1 and #2 are equivalent

Max Born - 1926; gave the modern interpretation