3. Experimental Basis of Quantum Physics, 1

lecture 13, September 27, 2017

housekeeping

- exam 1 is day after tomorrow
  - Friday, 29 September
  - Relativity and Thermodynamics
- Homework, chapter 3 in Thornton and Rex:
  - I moved some problems into the following week
- Shameless plug:
  - ISP220
- Honors option
  - we’re good.
  - I’m slow
- Gripes
  - by today

unravelling

the 19th Century

problems everywhere you look

quick survey...then details.

unravelling

the 19th Century

problems everywhere you look

quick survey...then details.

Albert Michelson
from his book, *Light Waves and Their Uses*, 1903

"

The more important fundamental laws and facts of physical science have all been discovered and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote...Many other instances [of 'apparent exceptions'] might be cited, but these will suffice to justify the statement that our future discoveries must be looked for in the sixth place of decimals.

very famous quote which he lived to regret

the pace picks up

The decade of 1888-1898 was the warm-up to rapidly changing circumstances

We’ll barrel through 11 separate catastrophes from this one decade

- then, I’ll come back to some of the details

1. specific heats

specific heats: satisfying and yet sometimes disturbing...

Two problems, gases and solids.

Remember, for a monotonic gas, Equipartion says:

- ***c_V/R* = 3/2**: for Helium: 1.52; Argon: 1.51 at room temperature...✔

But

- for H_2: 2.44; N_2: 2.45; O_2: 2.5... ✔;
- but...Cl_2: 3.02; HOH: 3.3; SO_2: 3.79...**?**
- if diatomic and "dumbbells," you expect $C_V/R = 5/2$

Maxwell worried about this:

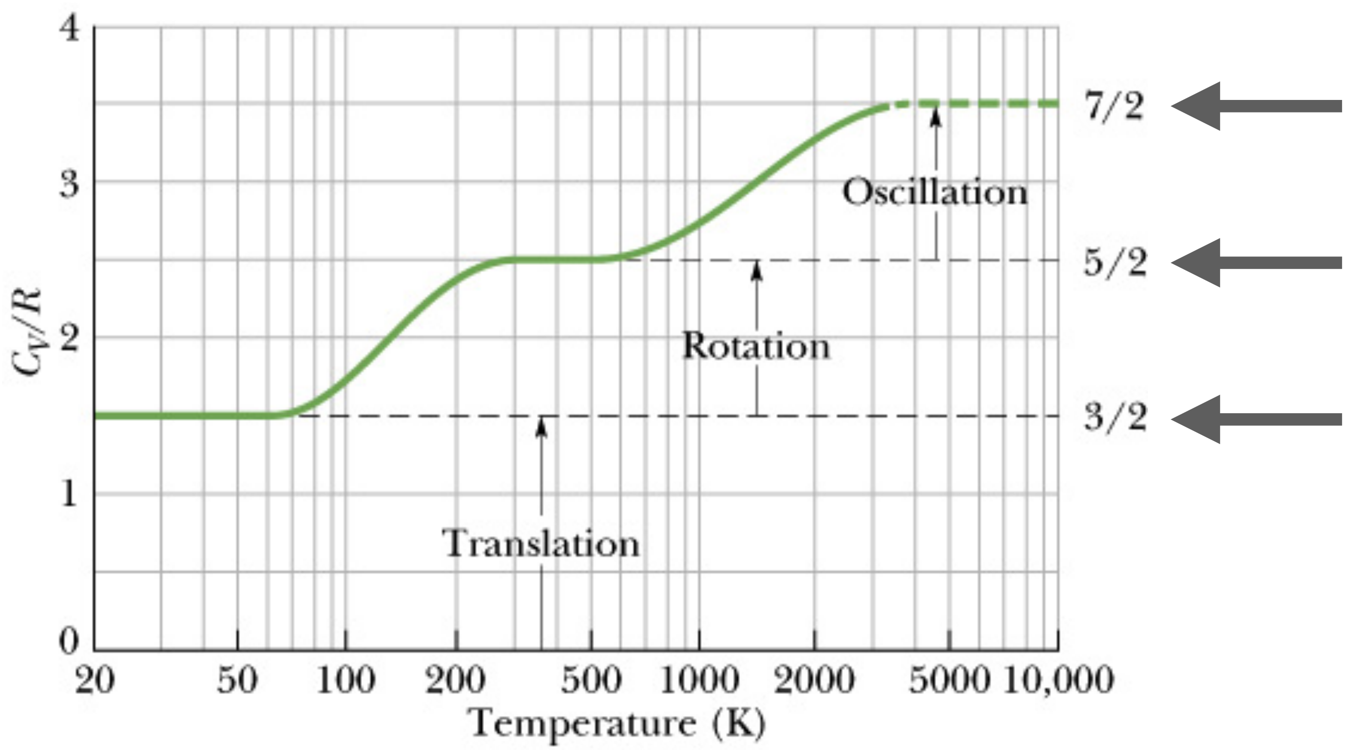
- "...what I have now put before you I consider the greatest difficulty yet encountered by the molecular theory." a talk from 1875 - there appeared to be missing vibrations, cV was sometimes too big...

that's not all...later, a strange temperature dependence was found

- "...it is a very mysterious phenomenon, and it seems as though as the temperature falls, certain kinds of motions 'freeze out'," James Jean, 1910.

heat capacity of H_2

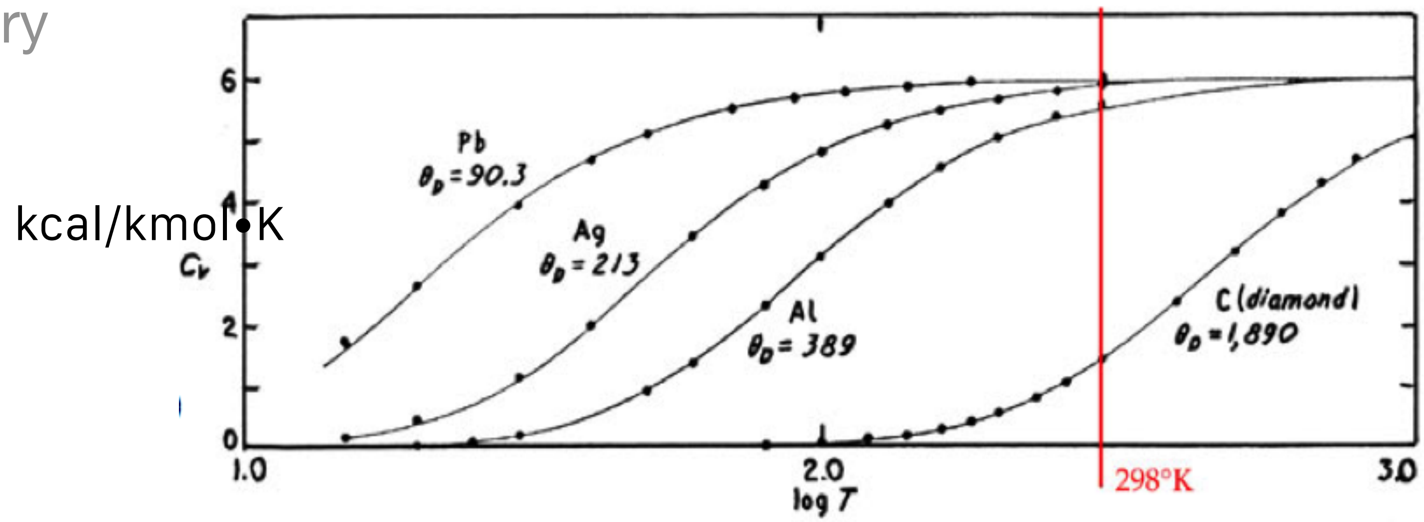
no classical explanation for the temperature variation



but, that’s not all

Specific heats of solids had been confused

for nearly a century



Lewis & Randall, *Thermodynamics*, Revised by Pitzer & Brewer, 2nd Edition, McGraw-Hill, 1961, p. 56.

again, two problems:

1. to account for the fact that many solids appear to approach the same value*
2. the temperature dependence at low T

*expect from Equipartition:

$c_V /n = 3/2\ R = 3/2\ (1.986)$

$= 6$ kcal/mol•K   called the Law of Dulong and Petit from 1817!

2. atomic spectra

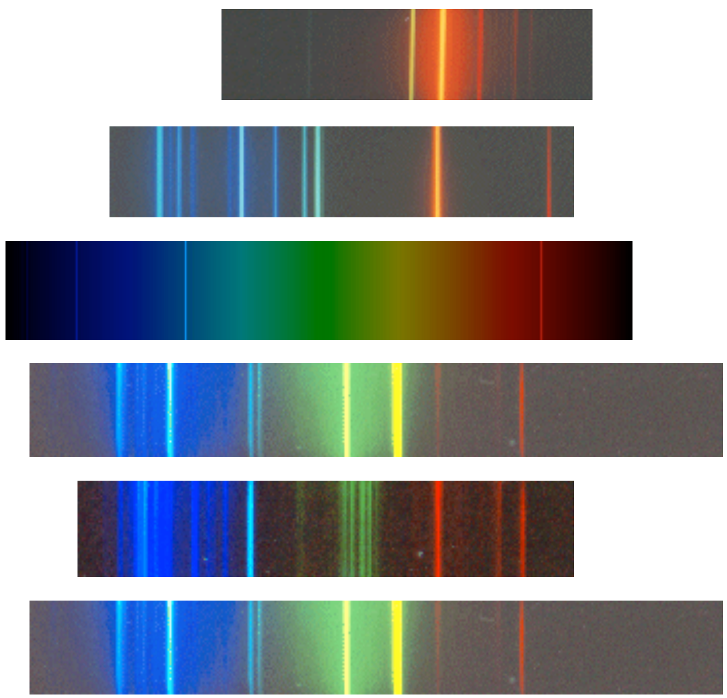
since 1880’s

There are two ways that matter emits electromagnetic radiation

- thermal radiation (coming)
- discrete line-emission

Kirchhoff and Bunsen first looked at hot materials with a prism

- saw regularities, which seemed to characterize individual elements



sodium

helium

hydrogen

mercury

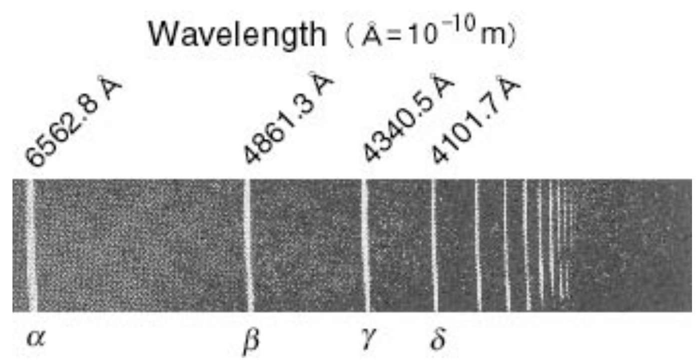
argon

mercury

hydrogen was simple

it appeared to quantifiable

done by a schoolteacher, Johann Balmer in 1885...for 5 lines



he found:

$$c\frac{9}{5}, c\frac{16}{12}, c\frac{25}{21}, c\frac{36}{32}, c\frac{9}{5} \Rightarrow \lambda = 3645.6\frac{n^2}{n^2-4}\text{Å}$$

so, is there a general formula?

In 1890 Johannes Rydberg and independently, Schuster found a complicated formula for many series

$$\frac{1}{\lambda} = R_{element}\left[\frac{1}{(m-a)^2} - \frac{1}{(n-b)^2}\right]$$

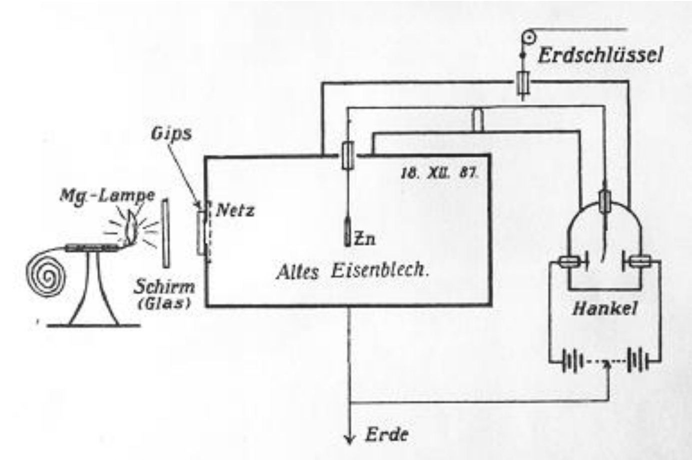
R, a, and b depend on the element
m is an integer that depends on the line series
n is an integer that is variable

with the Balmer relation being the simplest example:

$$\frac{1}{\lambda} = R_H\left[\frac{1}{2^2} - \frac{1}{k^2}\right]$$

R is the Rydberg Constant for Hydrogen, R = 1.096776 x 10^{-7} m^{-1}
k is an integer always larger than 2

3. photoelectricity



Grundversuch der lichtelektrischen Erregung.
Fig. 2.

A curiosity in Hertz's discovery of EM waves

- he covered the receiver gap with a cardboard box: a weaker spark
  - line-of-sight, ultraviolet light from the sending-gap affected the receiver strength
    - he did little else to study this

Herz's students and others experimented immediately

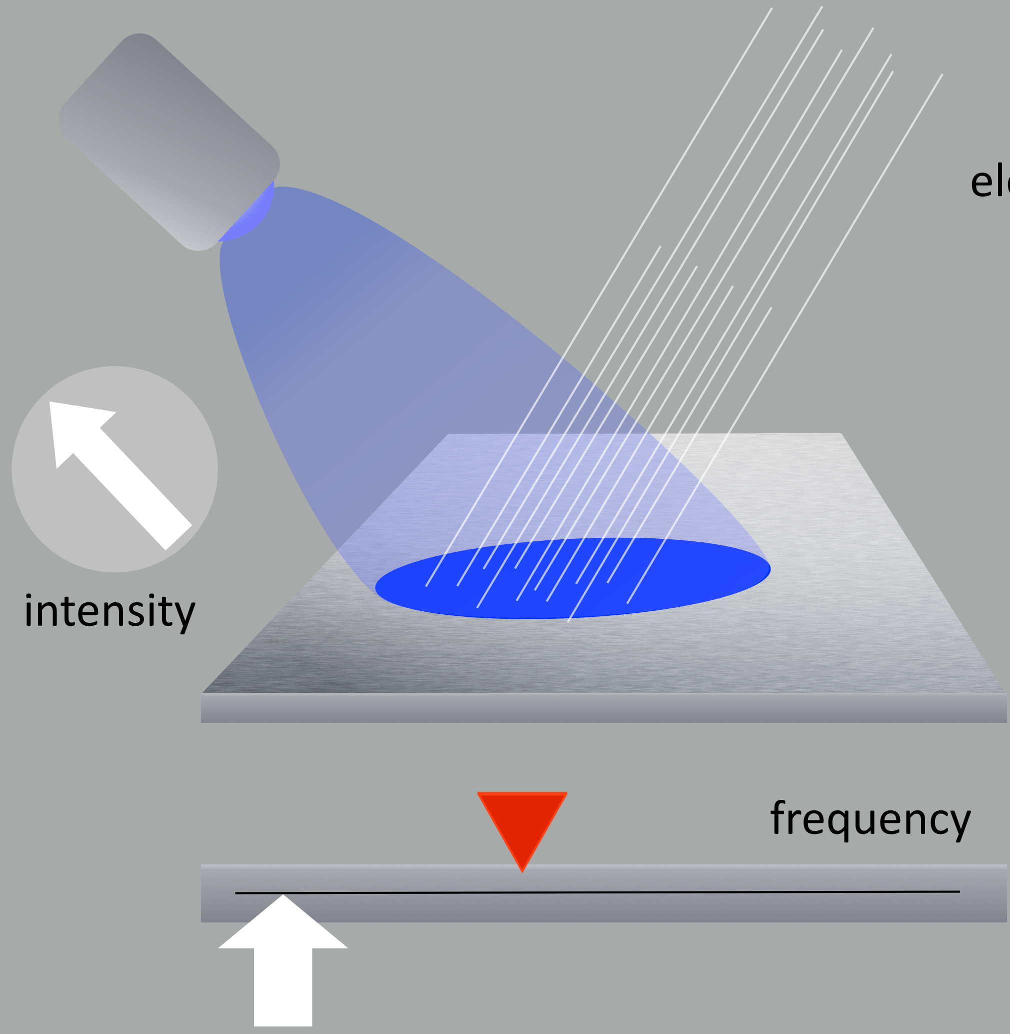
- illumination by a Mg lamp - ultraviolet:
  - a neutral plate of polished metal (zinc usually) became positively charged
  - negatively charged plate would lose its charge
  - while a positively charged plate would not

An actual current of "photoelectricity" could be produced

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

later

1899: J.J. Thomson: photoelectric current was electrons

1900: Philipp Leonard measured"e/m ratio": yes, electrons

visible light could eject photoelectrons from Na, the alkalis

Strange behavior:

a) change intensity: the strength of the photocurrent did not change

b) change the frequency: the strength of the photocurrent *did* change

below a minimum frequency, no emission of photoelectrons

c) switch light on and off quickly: photocurrent started/stopped immediately

Maxwell's EM theory:

a) would change,

b) would not change

c) would not necessarily change".

Photoelectricity not consistent with continuous energy of EM waves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BRK Brands
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4. the ether

we know this:

Stellar aberration?

- Ether stationary wrt earth

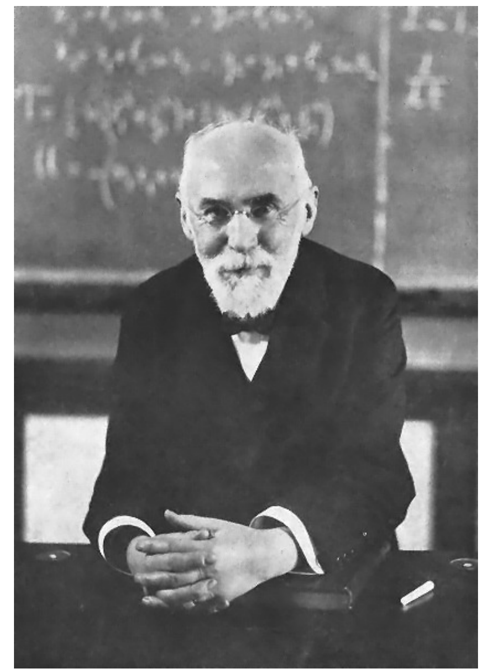
Michelson/Morley?

- Ether moving with earth

5. electron theory

our first Laureate: Hendrik Lorentz

- Dutch physicist held in huge esteem
    - weaned on Maxwell's theory
        - he fixed it where it didn't work, extended it
- Lorentz set out to establish a microscopic theory of electromagnetism
    - accounted for reflection and refraction of light and electrolysis



Hendrik Antoon Lorentz 1853-1928

electrons

Lorentz developed a theory of electrons, in advance of their discovery:

in Maxwell's theory, there are actually 2 electric fields and 2 magnetic fields:

one each for materials (D and H) and for vacuum (E and B)

Lorentz guessed that:

Electromagnetic radiation has, then, two particulate sources:

1. free charged particles accelerating **(in free-space)** and
2. bound charged particles–electrons–vibrating **(in matter)**

"Zeeman Effect"

Matter: negative electrons & positive ions

- bound, (accelerating) vibrating electrons: E and B fields,
- then external B field
  - could affect their motion
  - and thereby affect the spectra of gases

Peter Zeeman (student)

- Zeeman Effect
- —> sharing of the Nobel Prize in 1902

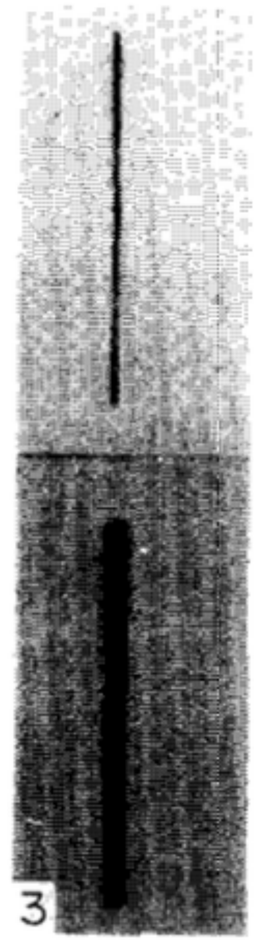

Peter
Zeeman
1895-1943

Zeeman Effect

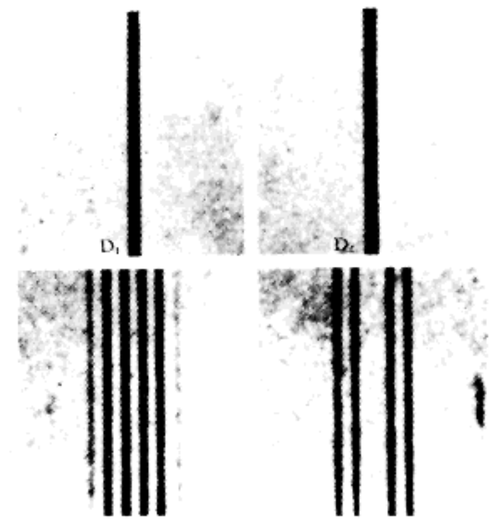
Confusing for quite a while

now, the "Anomalous Zeeman Effect"

Na



Na



H, "regular" Zeeman Effect

back to Lorentz

Two important and related issues converge on Lorentz

electron theory and ether

Electron theory was in the air:

"If we accept atoms for the chemical elements we cannot avoid concluding that also both positive and negative electricity is subdivided into certain elementary quanta which behave like atoms of electricity" Helmholtz, 1881.

what is mass?

"Self-energy" of the electron

Lorentz tried to show mathematically that the electron is nothing more than a little ball of electromagnetic energy

capable of deformation with velocity (like the MM experiment) &

with a mass as nothing more than an expression of the Newtonian inertia associated with the momentum content of the electron's own electromagnetic field

The mass of an electron turns out to be:

$$m_{em} = \frac{2}{3}\frac{e^2}{r_e c^2}$$

6. the electron

1897
J. J. Thomson

1856-1940

“

Could anything at first sight seem more impractical than a body which is so small that its mass is an insignificant fraction of the mass of an atom of hydrogen?

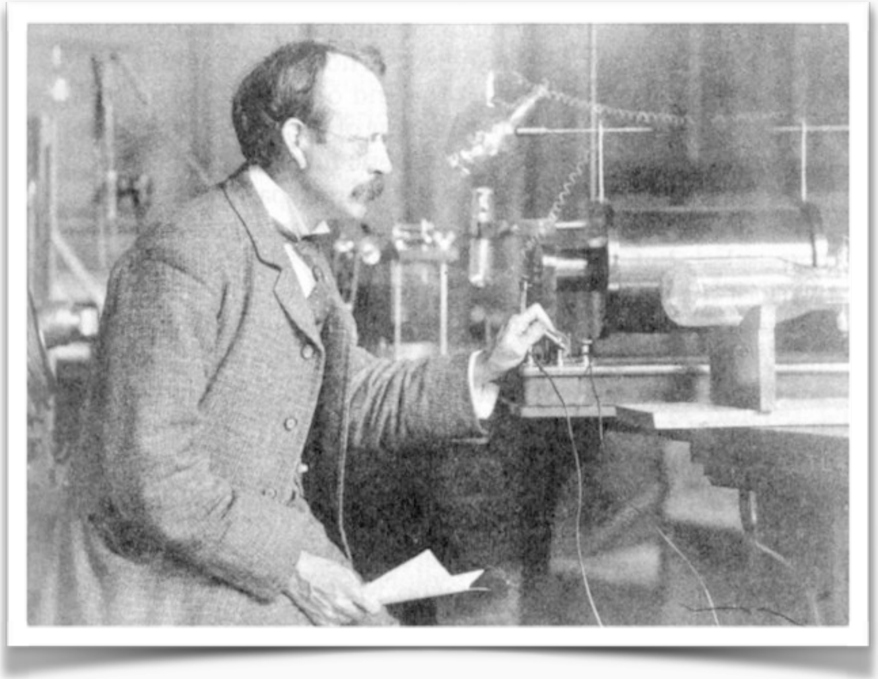
What are these particles? Are they atoms, or molecules, or matter in a still finer state of subdivision?

J.J.’s confusion was shared in 1897.

"J.J. was very awkward with his fingers, and I found it very necessary not to encourage him to handle the instruments! But he was very helpful in talking over the ways in which he thought things ought to go."

H. F. Newall, onetime assistant to the young Professor Thomson.

everyone studied cathode ray tubes



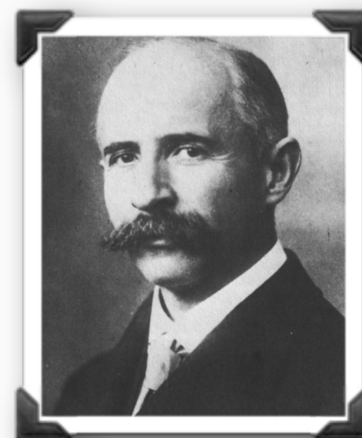
technologies enabled new experiments

J.J. enjoyed:

1. better vacuum and better batteries

2. an un-prejudiced mind.
   German, Walter Kaufmann did everything better than JJ

except open his mind.

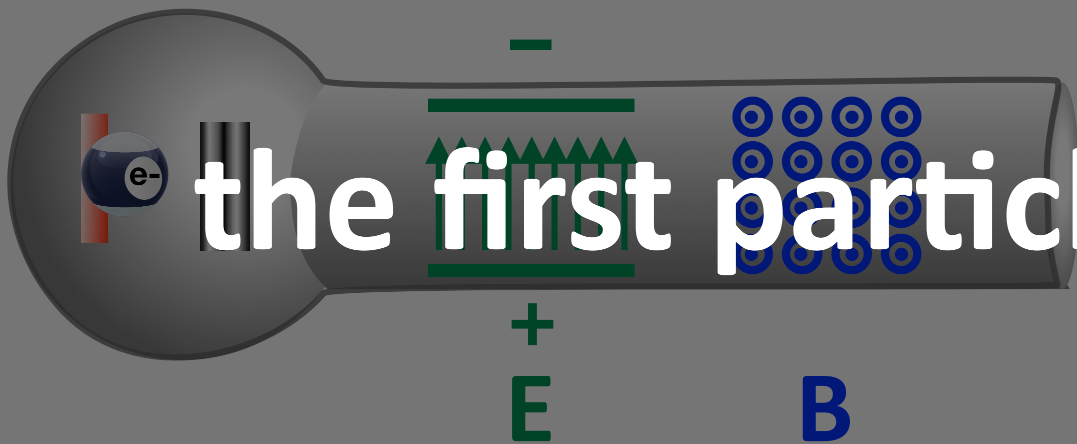


Walter Kaufmann (1871-1947)

JJ's experiment

presumed particles

presumption of particles



the first particle accelerator!

The measurement is the ratio of the charge to the mass:

if you assume that the beam is made of particles.

Nobel 1906

The Nobel Prize in Physics 1906
J.J. Thomson

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The Nobel Prize in Physics 1906

Joseph John Thomson

Prize share: 1/1

The Nobel Prize in Physics 1906 was awarded to J.J. Thomson *"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases"*.

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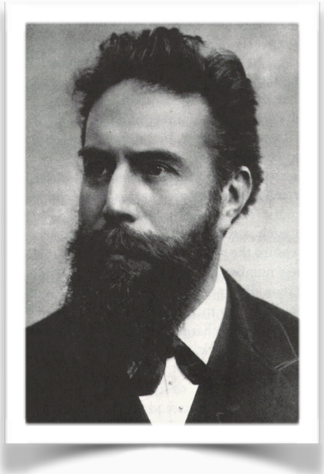
then, it gets really strange.

7. x-rays

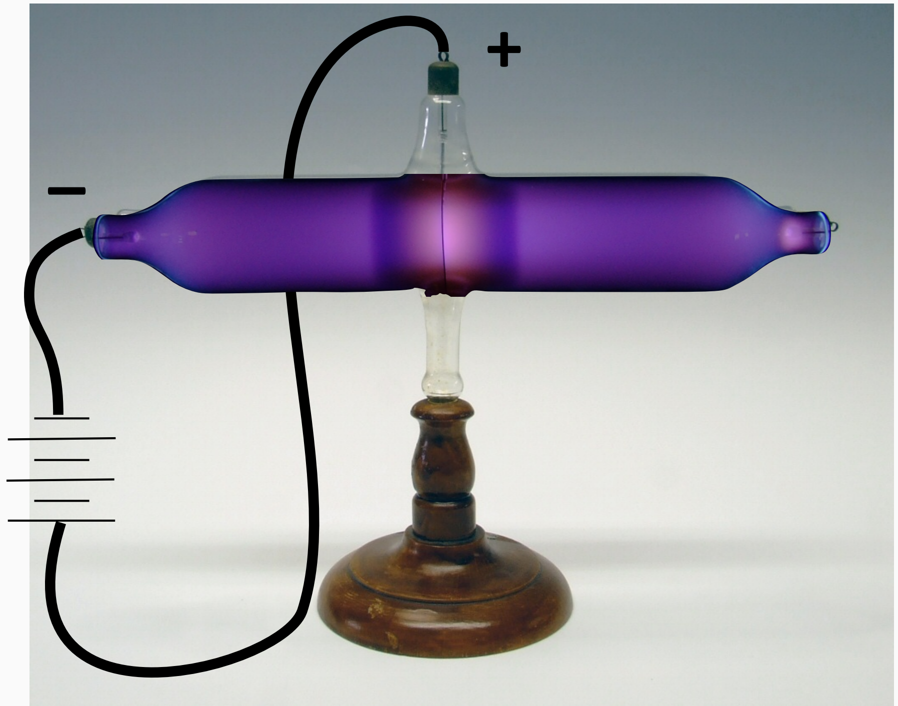
1895 Wilhelm Roentgen

1845-1923



“Roentgen has really gone crazy.” ...what Wilhelm Roentgen worried when at the age of 50 he found something unusual in his lab in Wurzburg, Germany.

Everyone studied “cathode ray tubes”–”Crookes Tubes”



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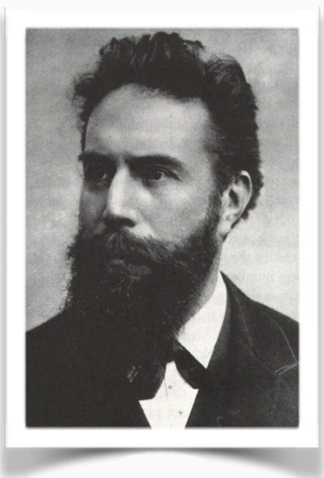

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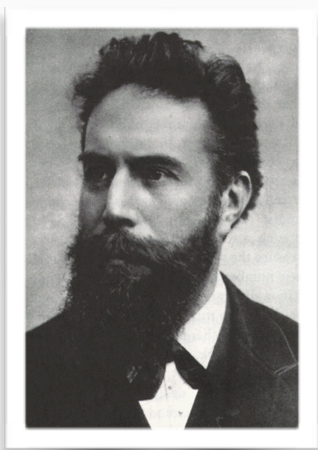

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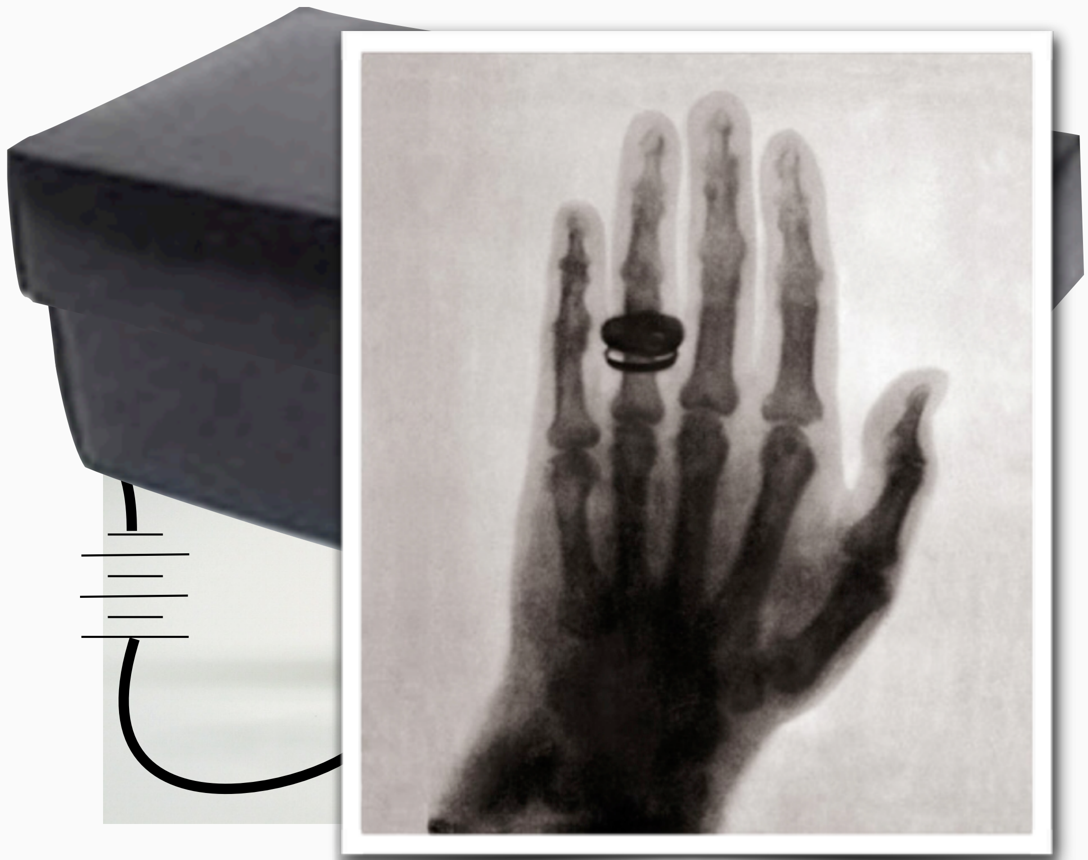
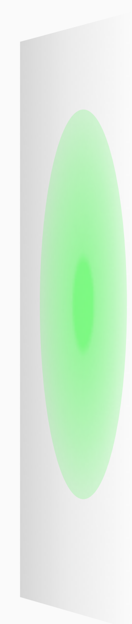




word got out

he spilled the beans

after 7 exhausting weeks

January 1, 1896 he circulated a picture of the bones of his hand and a description of his experiments: **called them "X."**

Within weeks, it was reprinted in *Science*, *Nature*, the *French Academie des Sciences* and other journals…announced at a meeting in Paris (on his behalf)

Within a week of the Paris announcement, confirmation occurred in 4 labs

Within 5 weeks, X-Rays were used to set the broken arm of a boy in Dartmouth

Within a year, a thousand papers were published

within 4 months, Edison is manufacturing

Wilhelm Roentgen on his discovery...

“

When you saw the screen shining ,'What did you think?', asked a reporter. 'I did not think, I investigated.' was the reply from Roentgen. 'What is it?', the reporter pressed. 'I don't know,' was the reply.

“In a few days I was disgusted with the whole thing. I could not recognize my own work in the reports any more. for exactly four full weeks I have been unable to make a single experiment! Other people could work, but not I. You have no idea how upset things were here.

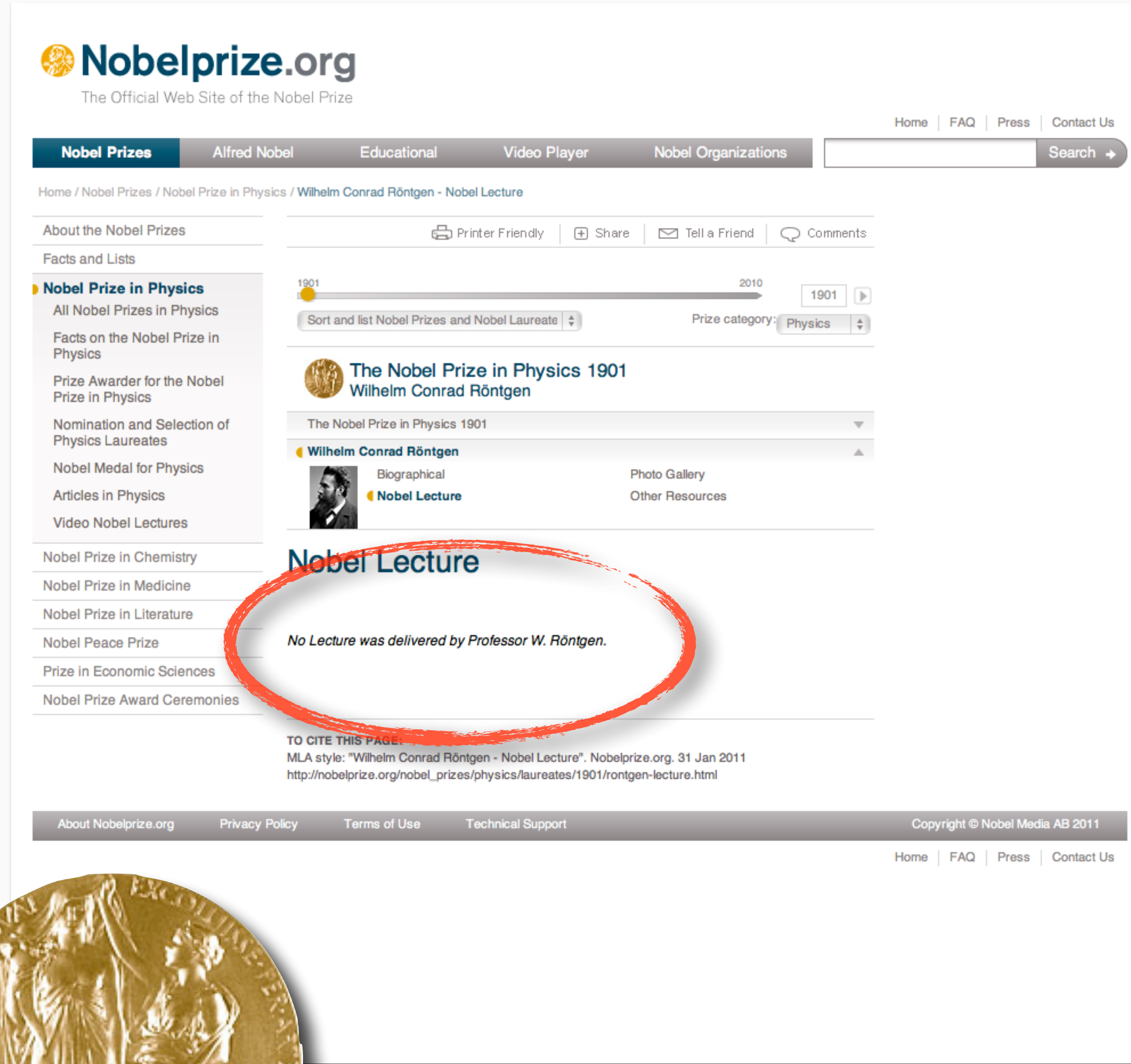
our first Nobel

1 talk

1 publication

no profit

suffered terribly during WWI



then, it gets really strange.

8. radioactivity

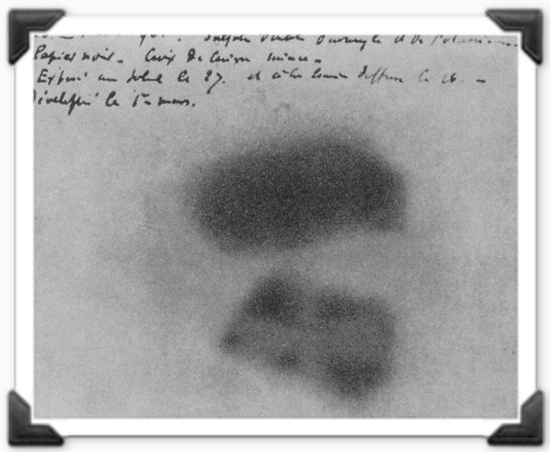
1896 Antoine-Henri

1852-1908

In the audience when X-rays were announced...

Expert in phosphorescence...thought X-rays were phosphorescence. wrong.

Wrapped up piece of Uranium when it got cloudy in Paris. When he unwrapped it:



Energy created out of nothing?

“Becquerel Rays”...didn’t catch on.

But: the idea of matter spontaneously emitting energy did!

He studied it and found the emanations ionized air and could be deflected by a magnet...so, it consisted of charged particles & not X-rays

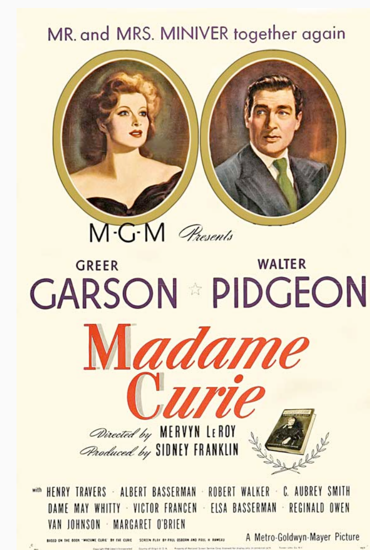
then, it gets really strange.

9. extreme radioactivity

1898
Marie Skodowska Curie

1857-1934

believe it or not
true-love stories in physics are rare!



set out to quantify

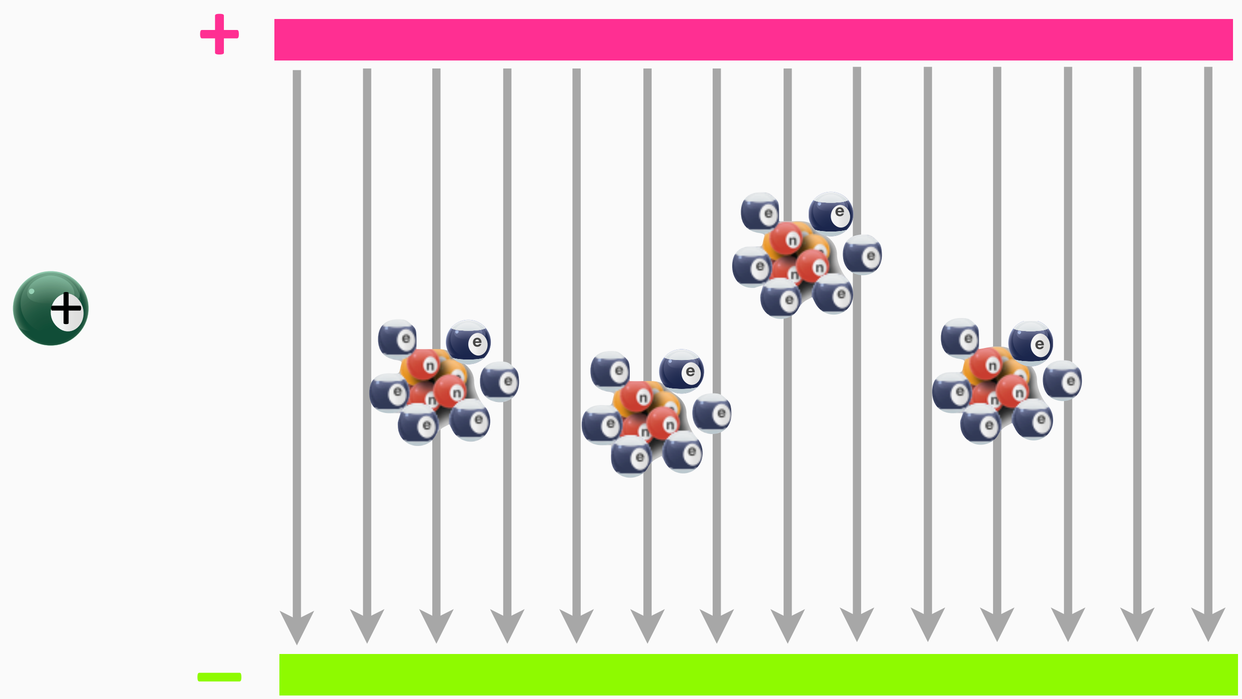
Ionizing radiation: Becquerel had found that the phenomenon of Uranium emissions would cause air to become **ionized**.

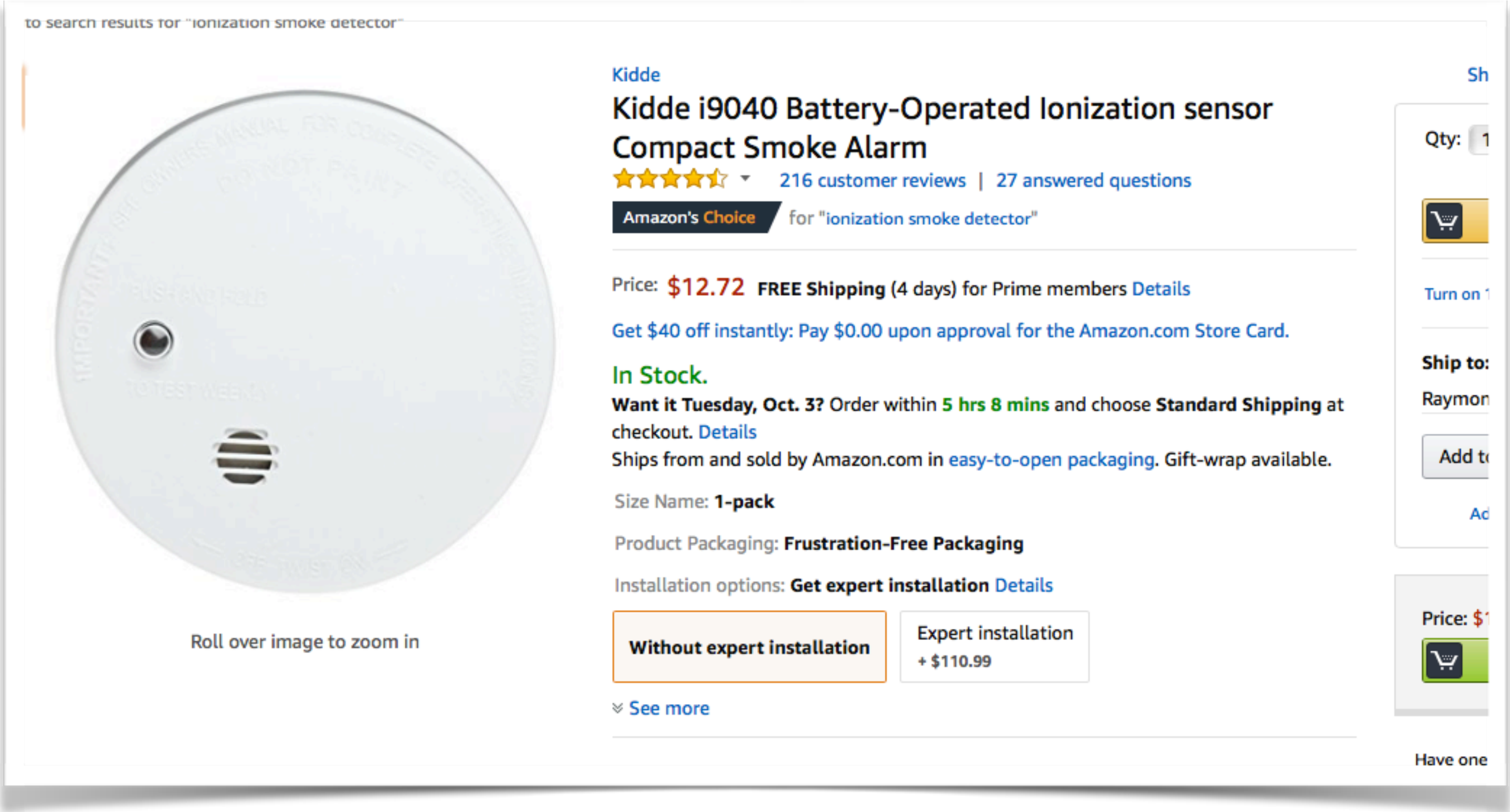
Madame Curie used that idea:

Becquerel rays

Marie built a new kind of apparatus for her PhD thesis

a current!




to search results for "ionization smoke detector"
Kidde
Kidde i9040 Battery-Operated Ionization sensor Compact Smoke Alarm
216 customer reviews | 27 answered questions
Amazon's Choice for "ionization smoke detector"
Price: $12.72 FREE Shipping (4 days) for Prime members Details
Get $40 off instantly: Pay $0.00 upon approval for the Amazon.com Store Card.
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See more
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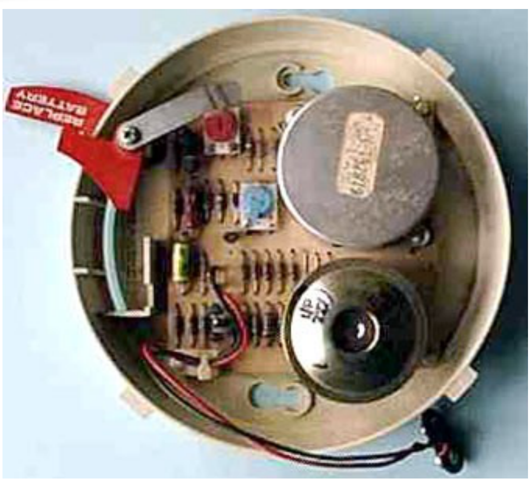
Price: $
Have one

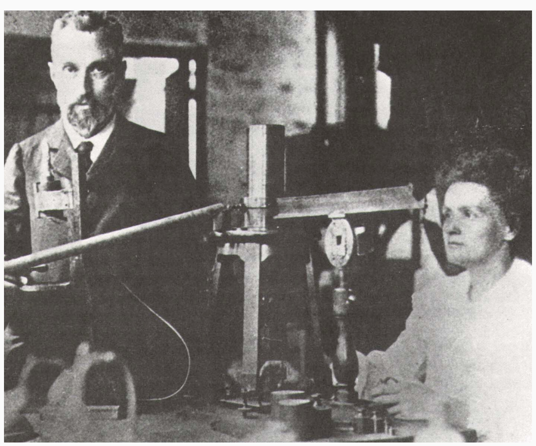


piezo electricity

apply a force to some crystals

get a voltage

Discovered by Pierre Curie and his brother



balance is created by adjusting the weight

piezo electric crystal - & a weight

creates charge

creates charge

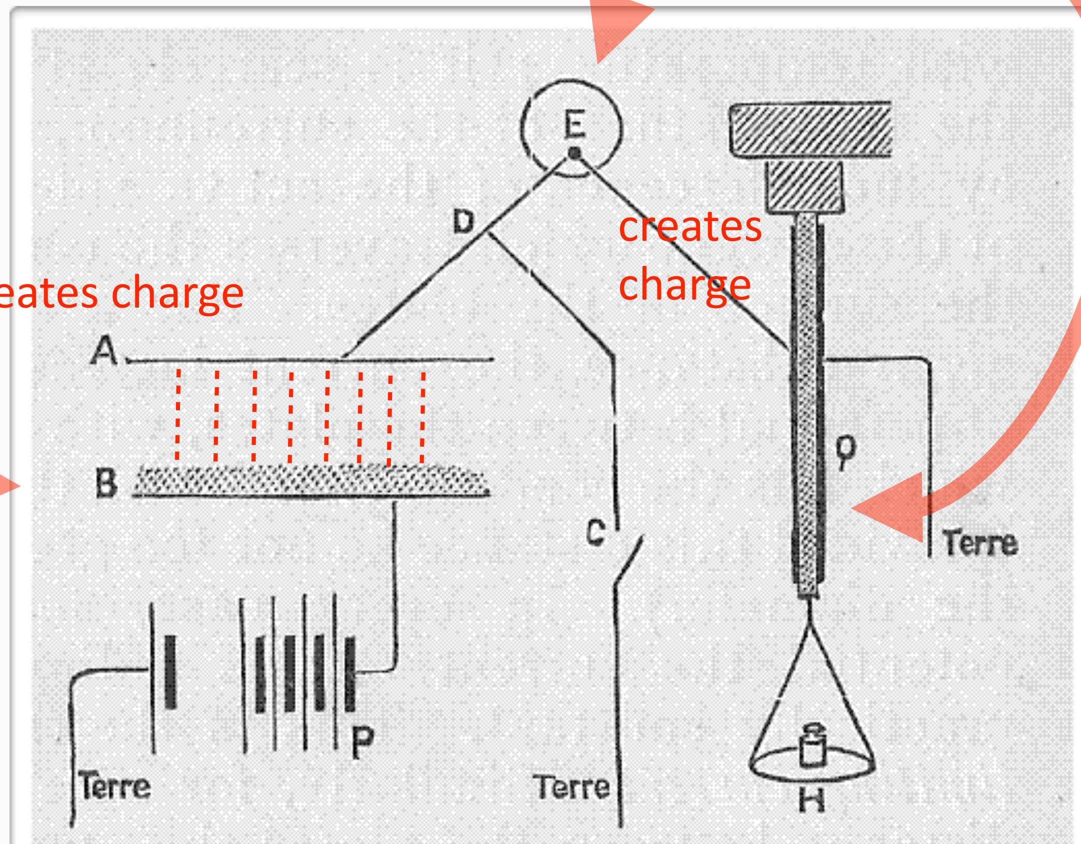


FIG. I.

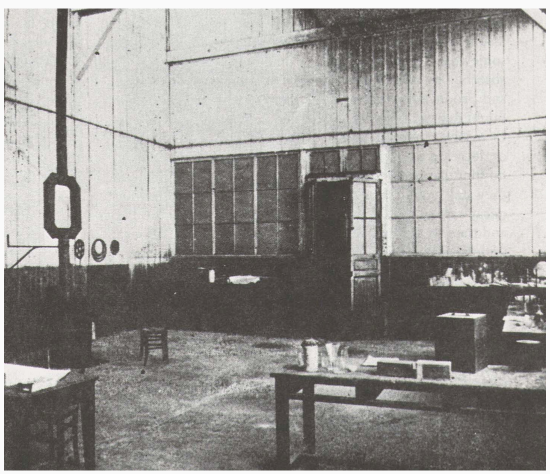
a radioactive substance inside of a parallel-plate capacitor

they found something else

They found a surprising thing:
pitchblend…an ore which contains concentrations of UO_2 was more radioactive than uranium by itself

"This fact is a very remarkable and leads one to believe that these minerals contain an element which is much more active than uranium."

She and Pierre began the systematic study of the relative radioactivity of whatever they could chemically isolate in the pitchblend
Announced the discovery of Po (Polonium) and Ra (Radium). Then…they had to find it.



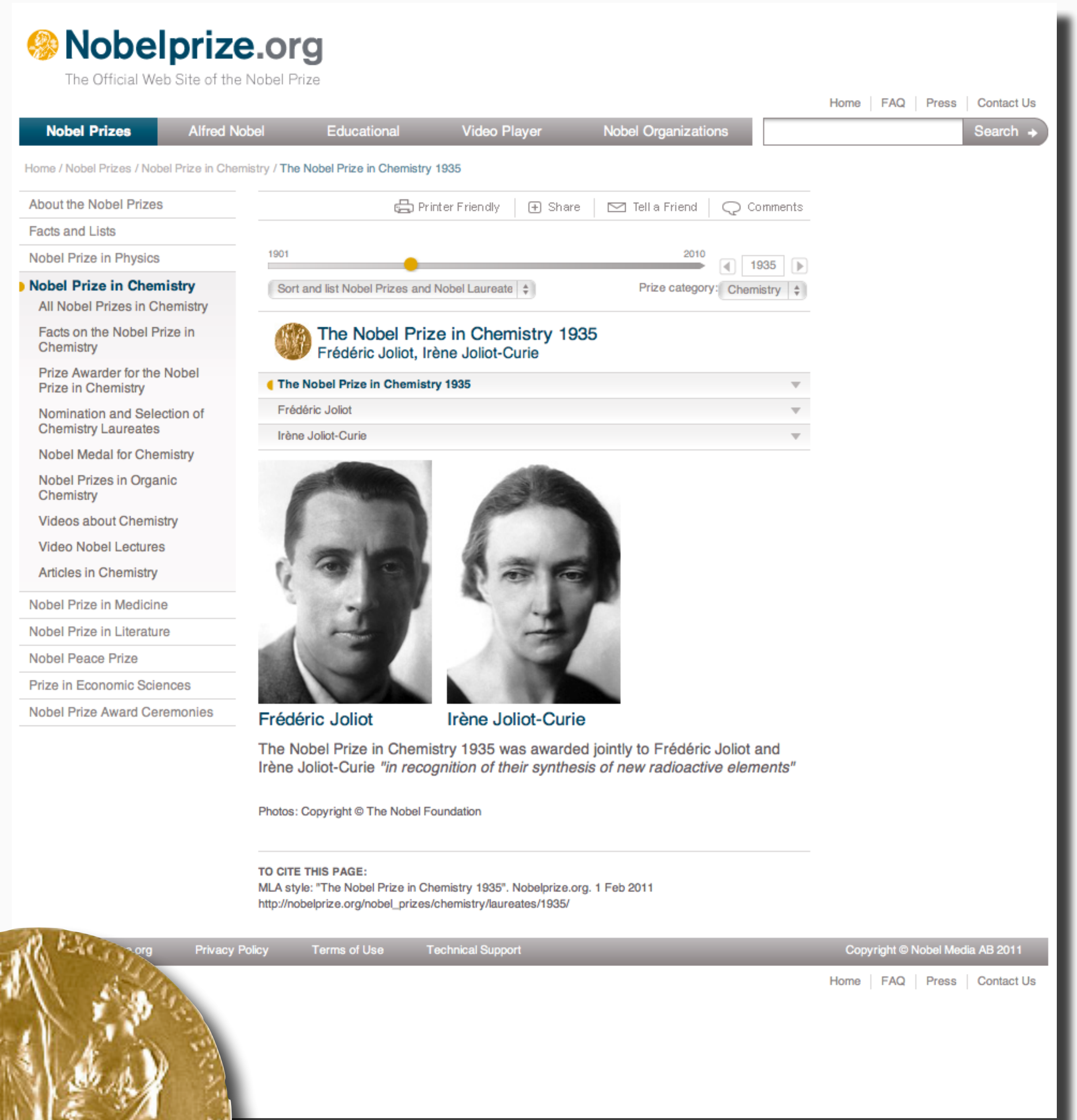
1900, 3 years later:

Nobel 1903

tragically, Pierre killed in a street accident 1906

BTW

their daughter also...



part of
Paris still