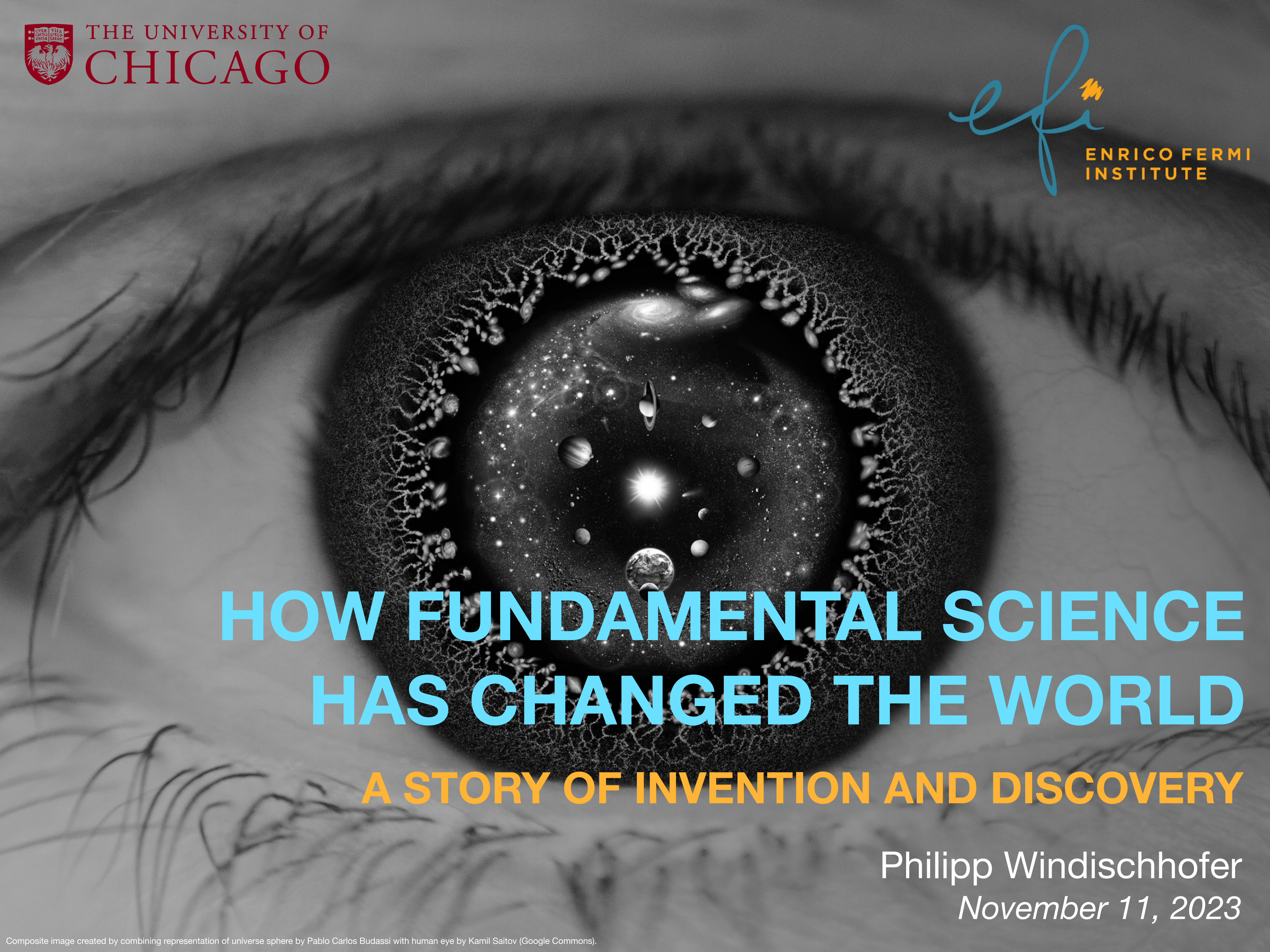

THE UNIVERSITY OF CHICAGO

ENRICO FERMI INSTITUTE

HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD

A STORY OF INVENTION AND DISCOVERY

Philipp Windischhofer

November 11, 2023

Composite image created by combining representation of universe sphere by Pablo Carlos Budassi with human eye by Kamil Saitov (Google Commons).

Reaping the fruits of hard work

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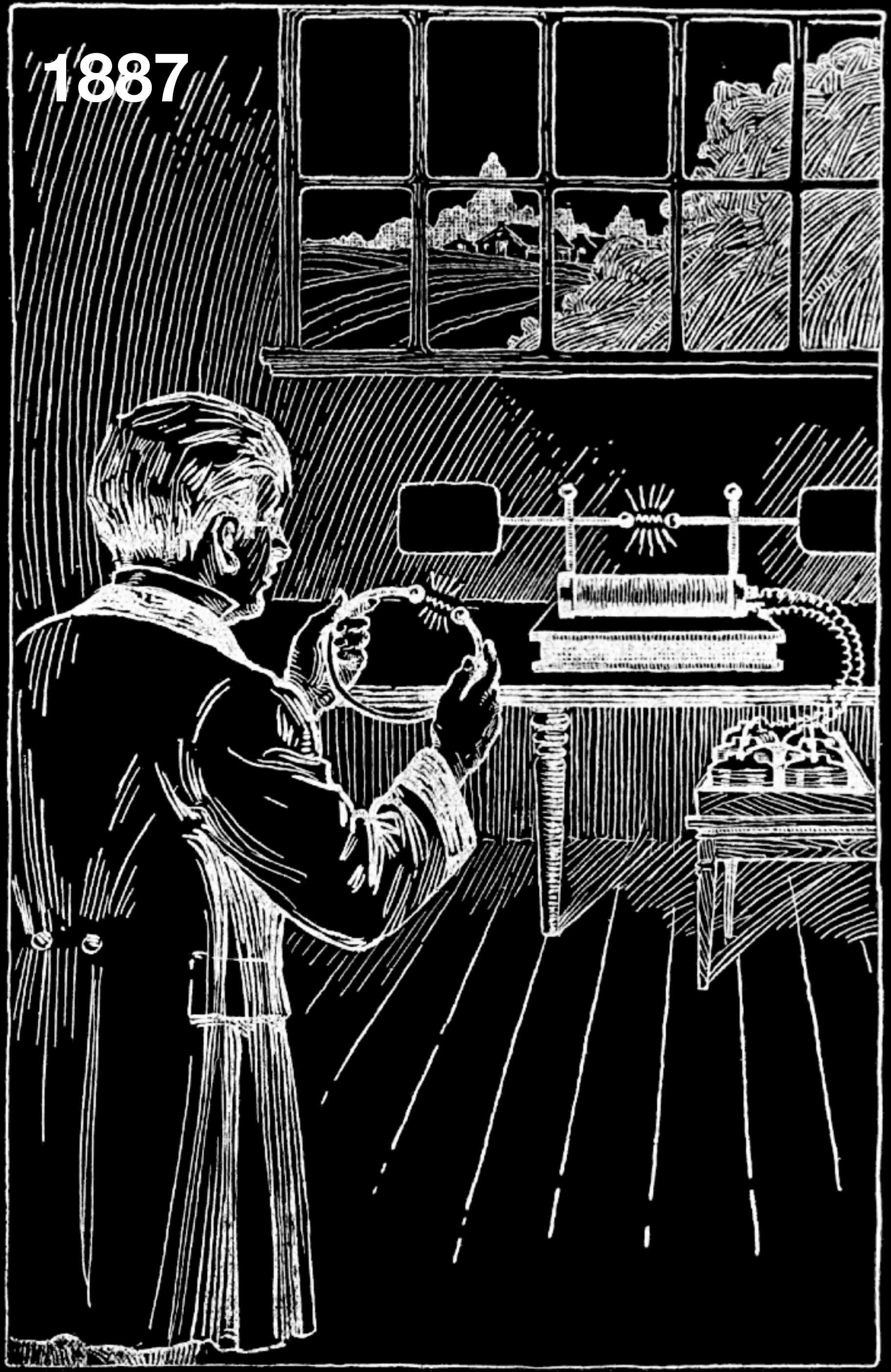

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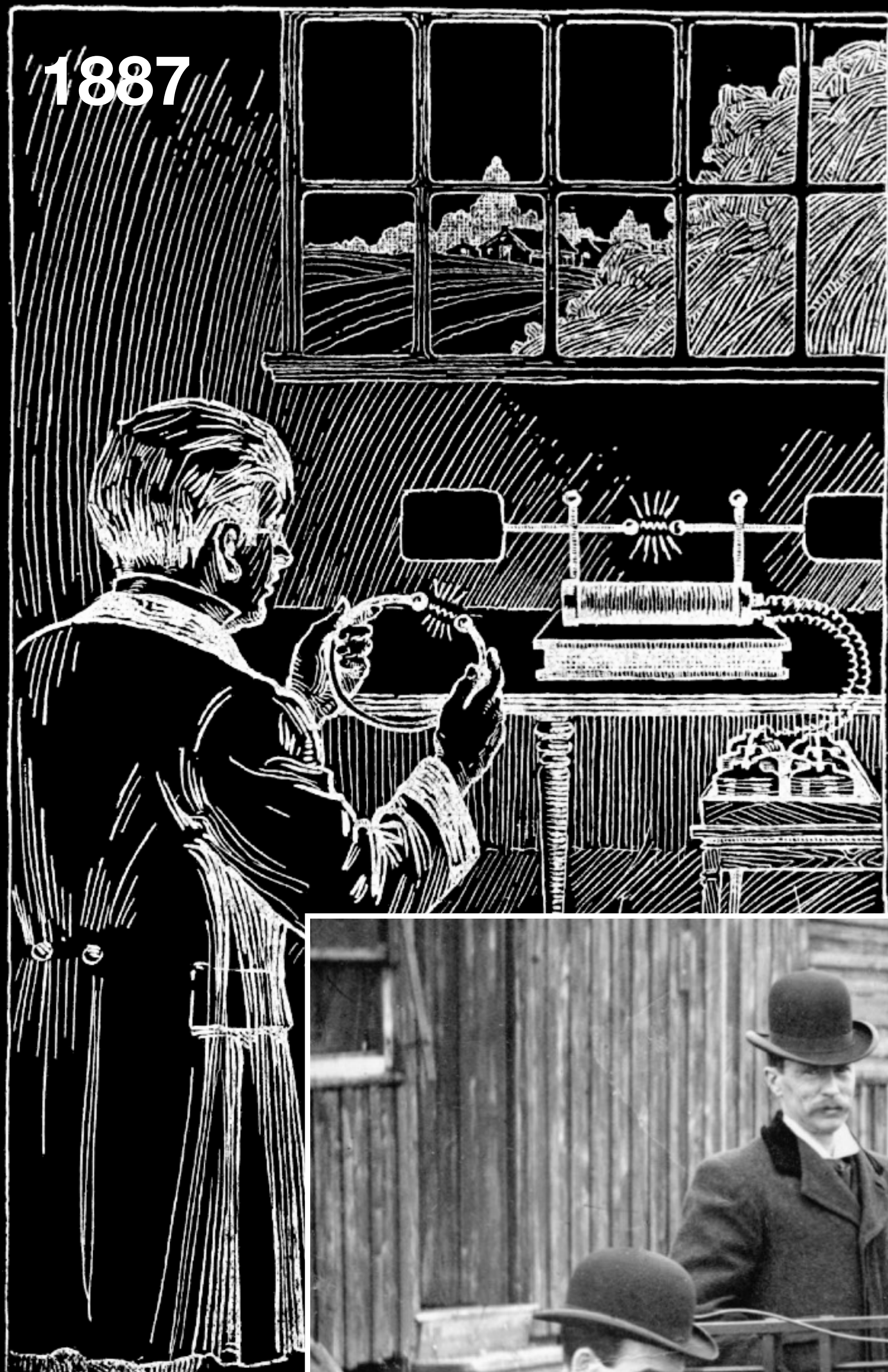

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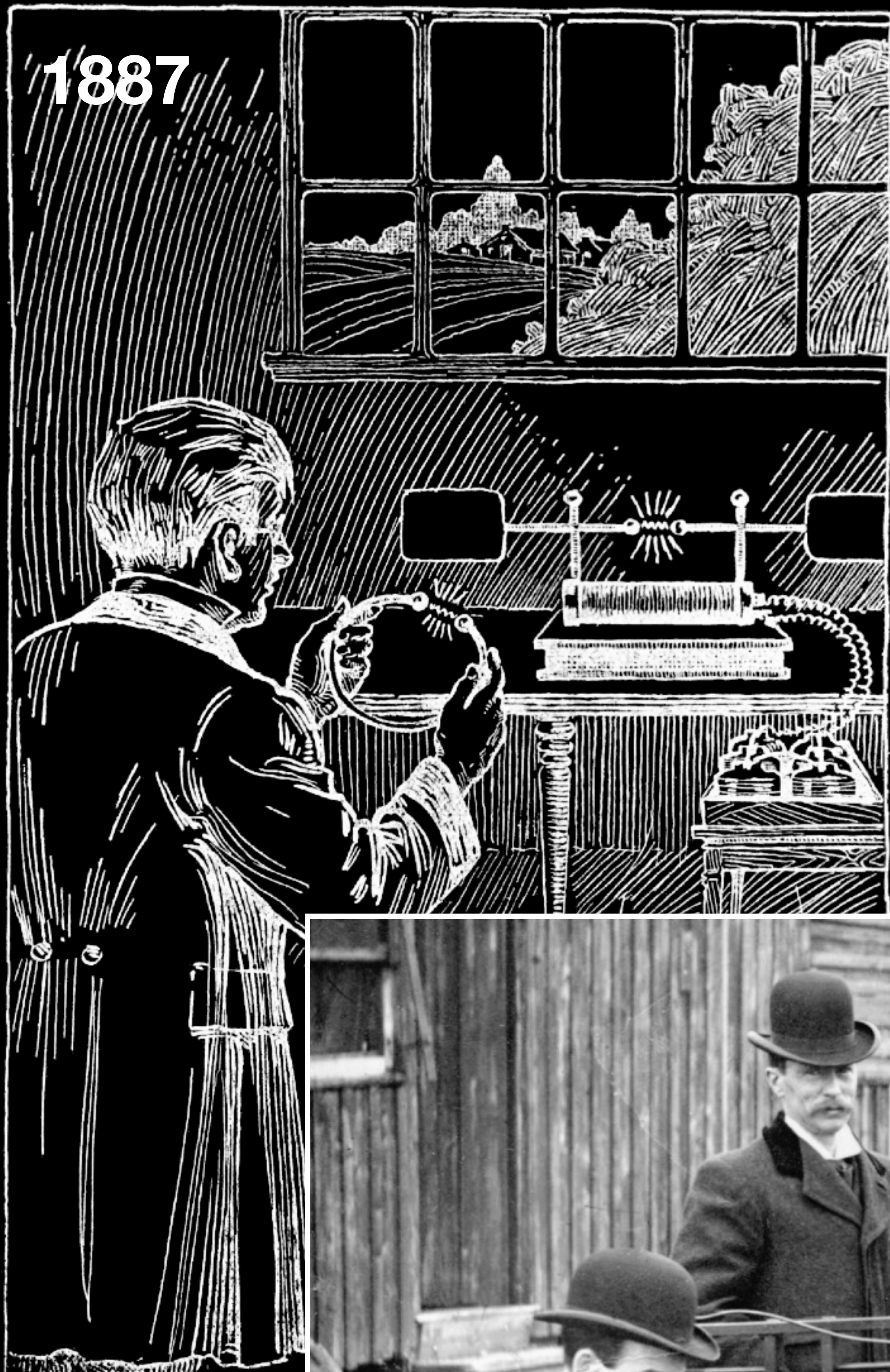
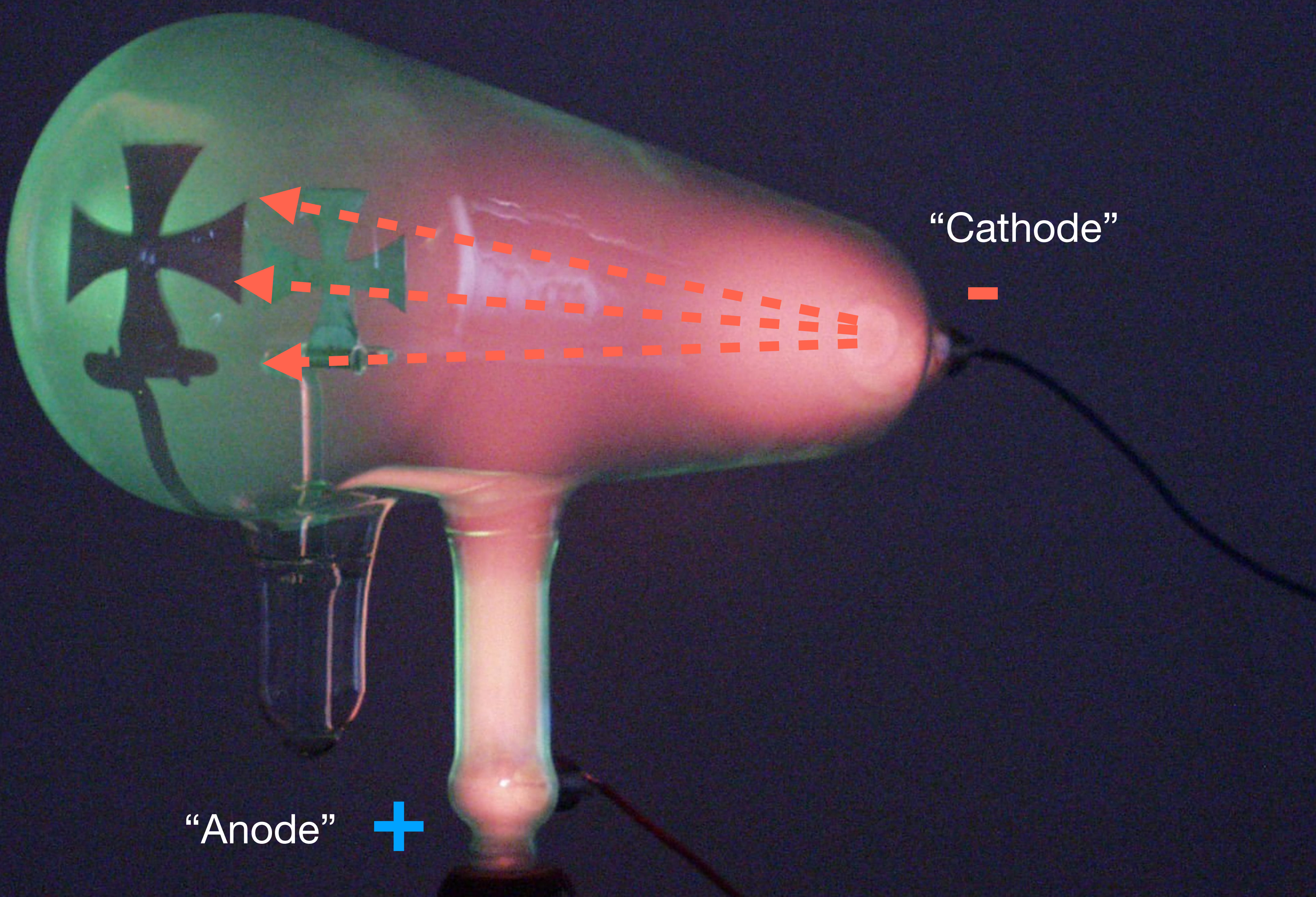


A new perspective on electricity

"Cathode Rays"



A new perspective on electricity

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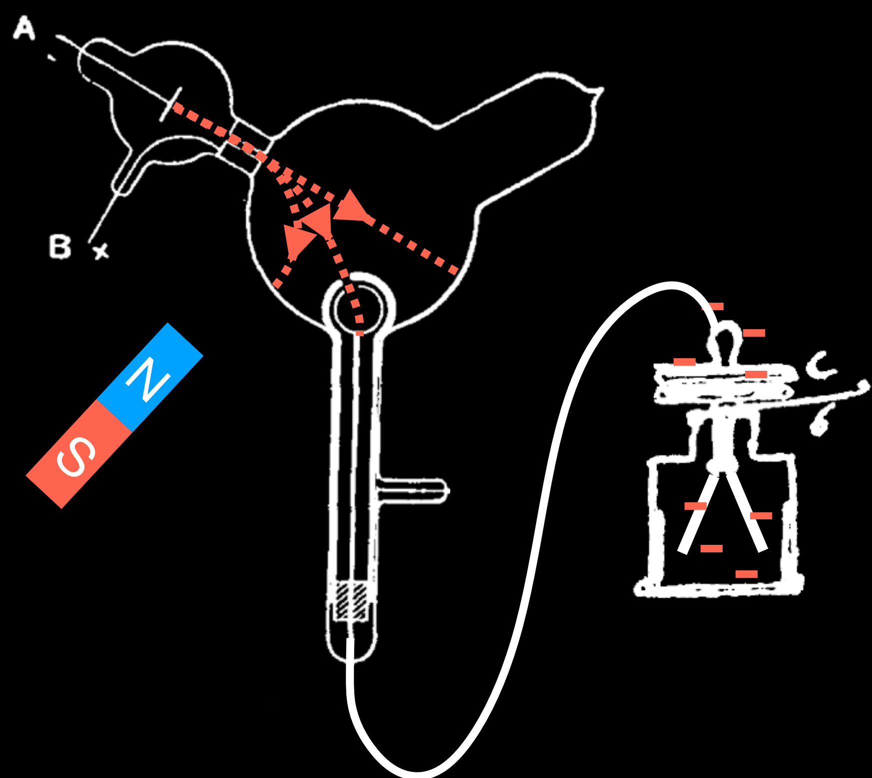
"Cathode rays" behave just like electricity!

A new perspective on electricity



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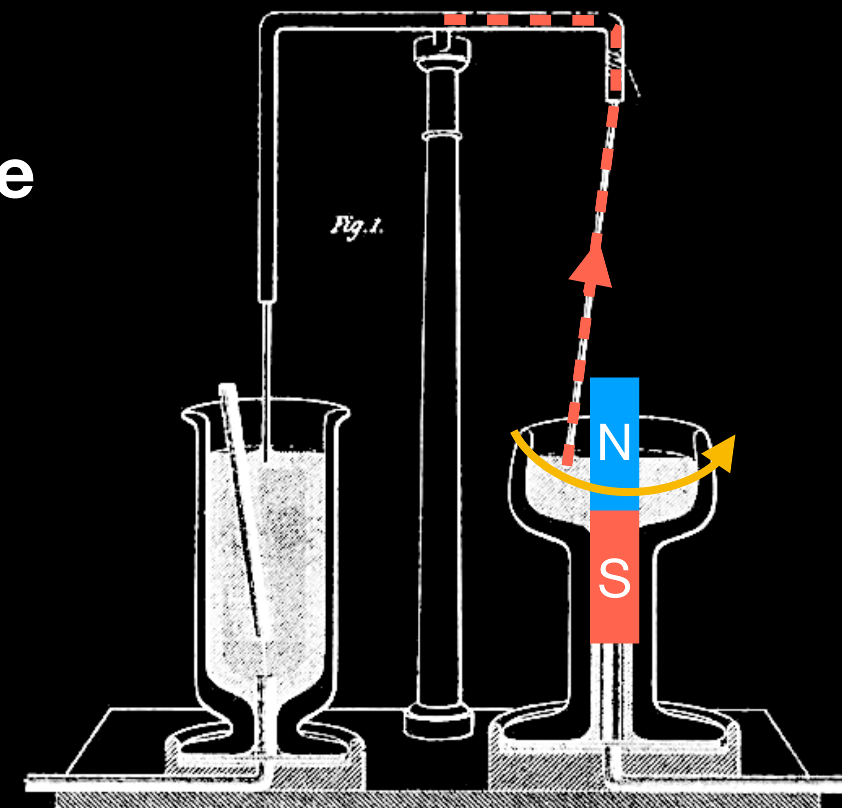
← *Magnetic deflection* →



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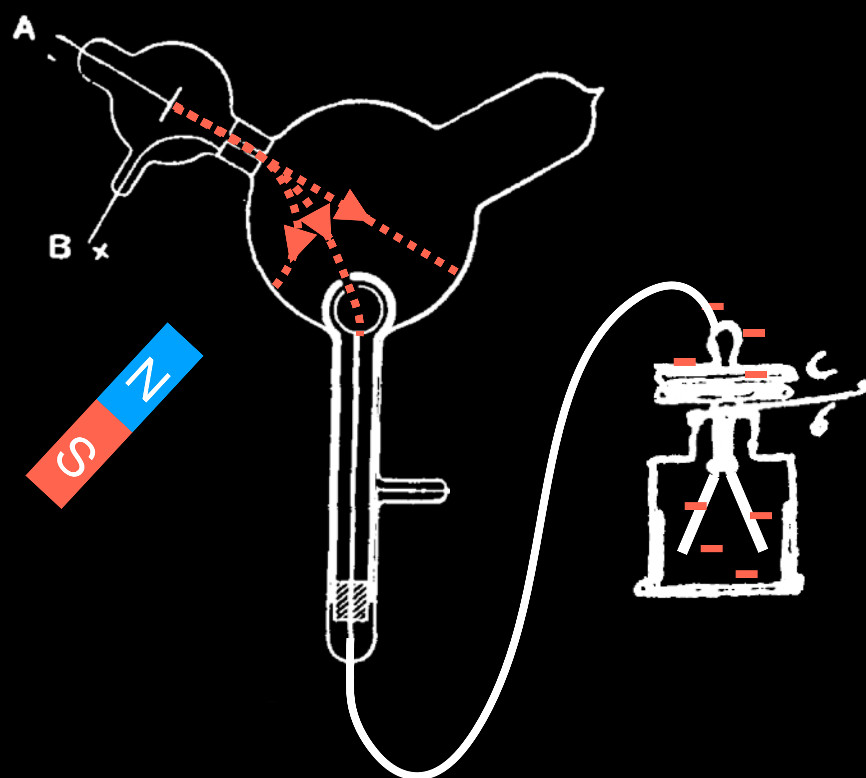

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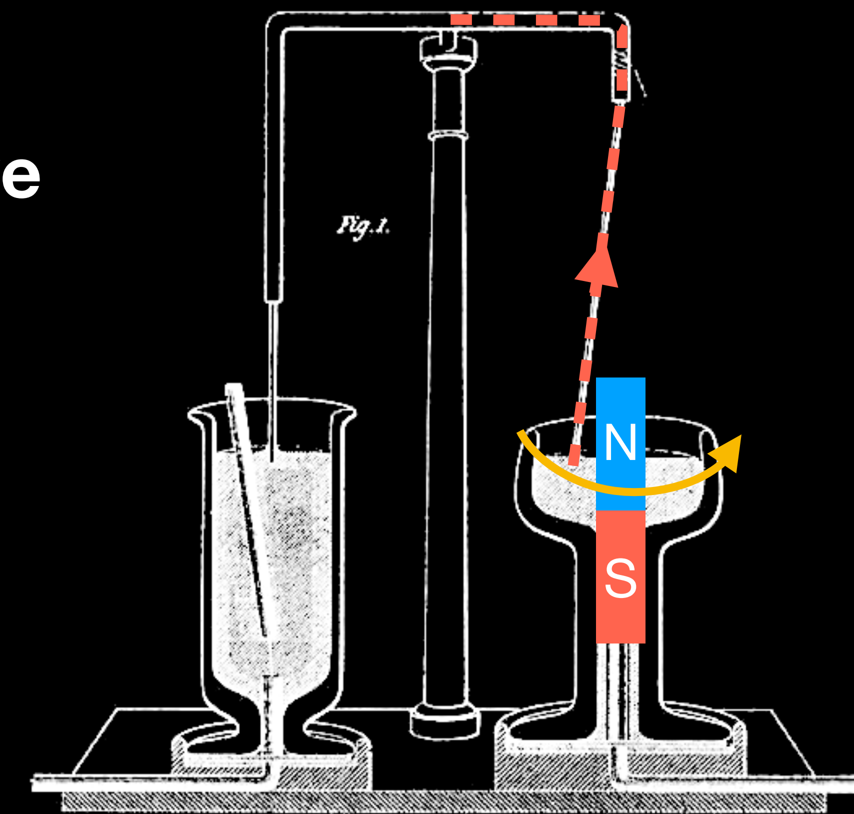
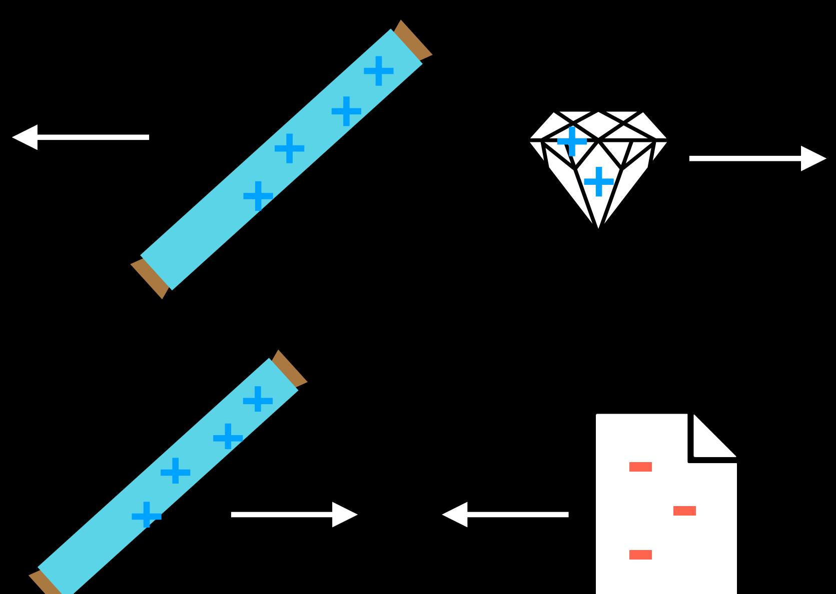
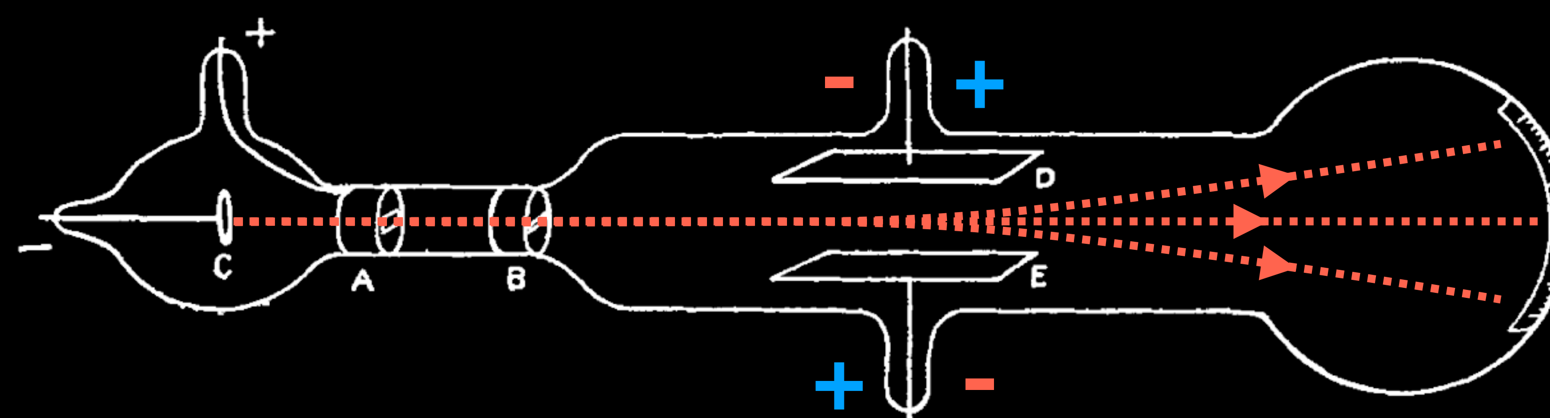
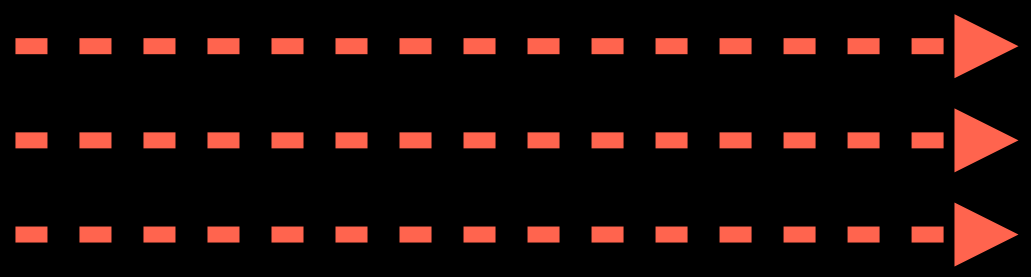


Magnetic deflection

Electric deflection







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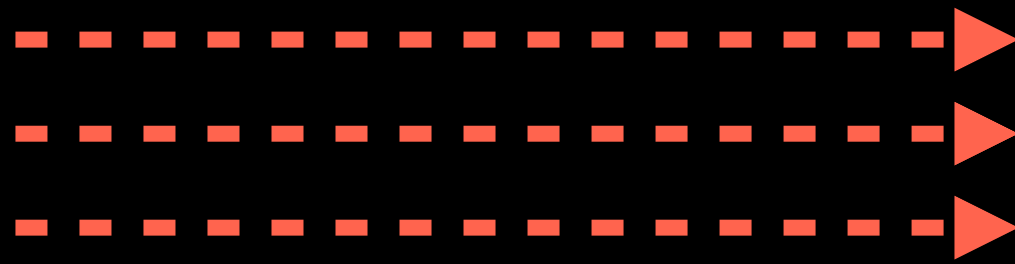

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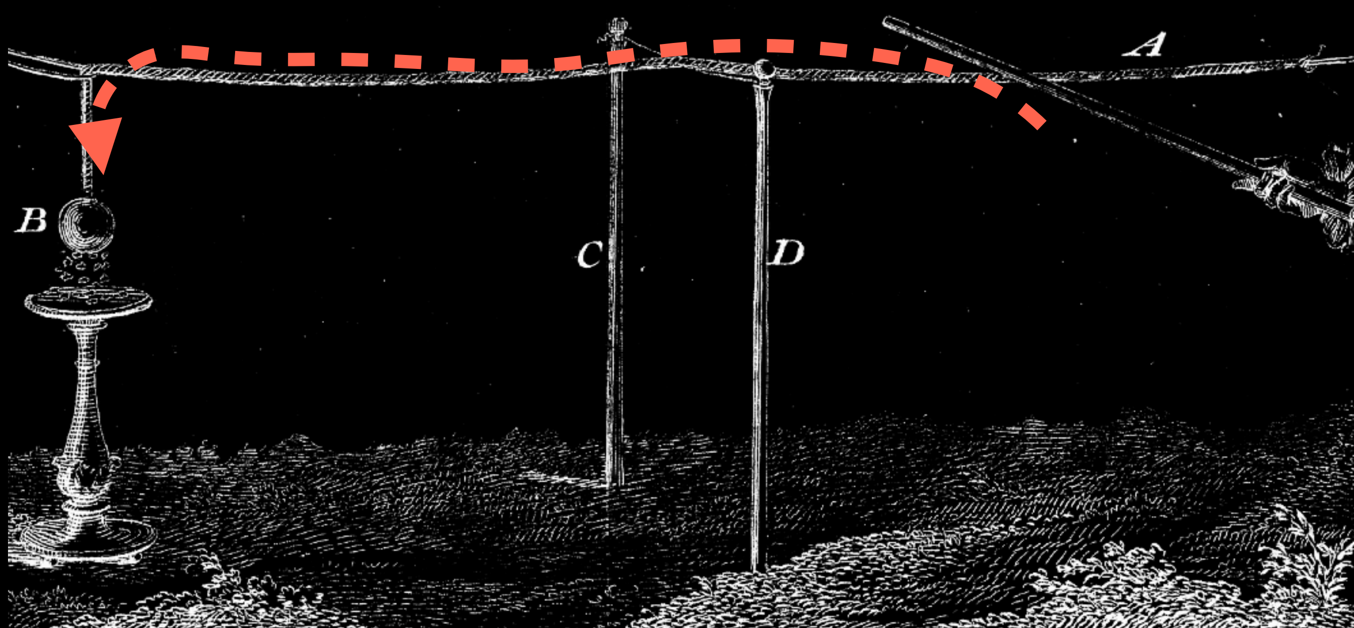
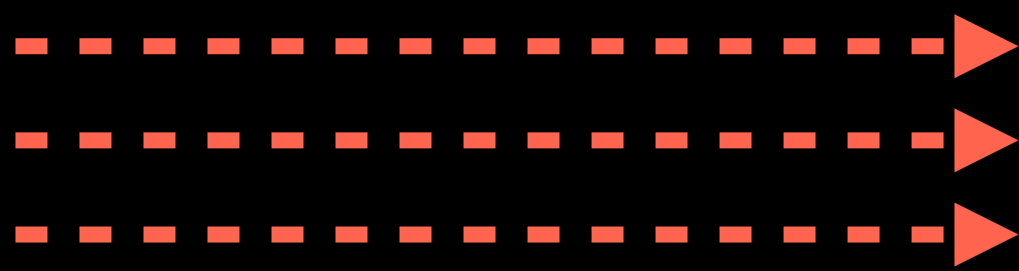


Electricity flowing
in a wire



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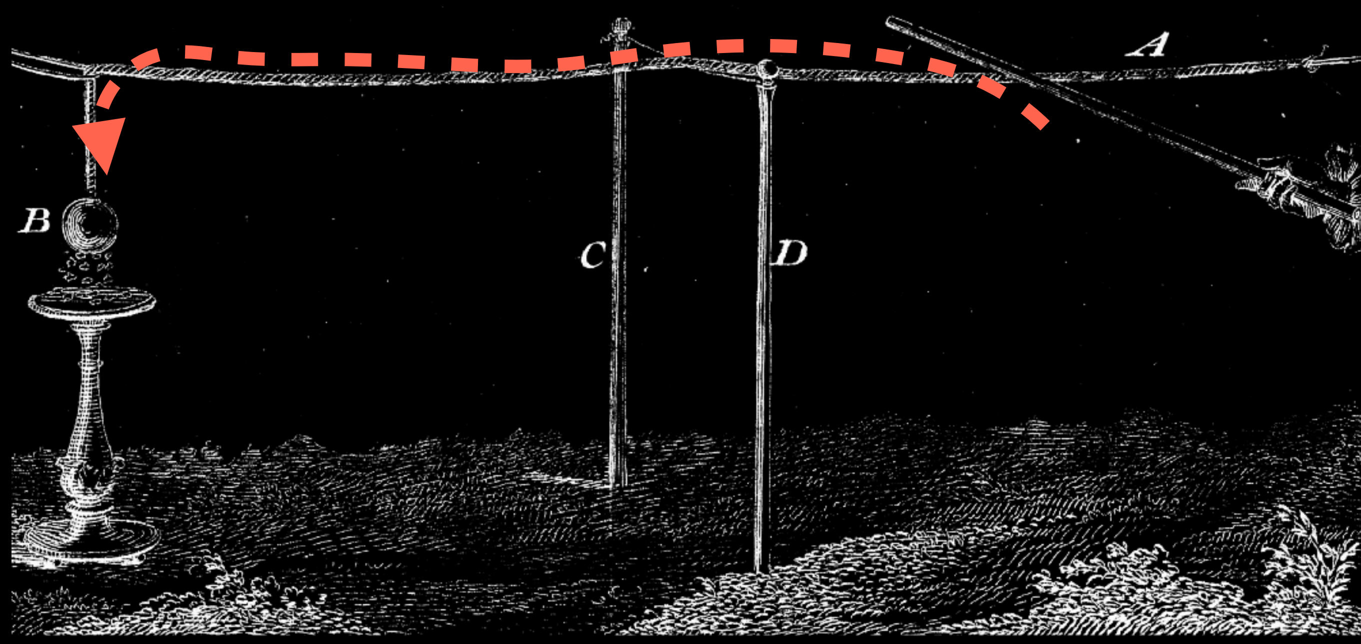

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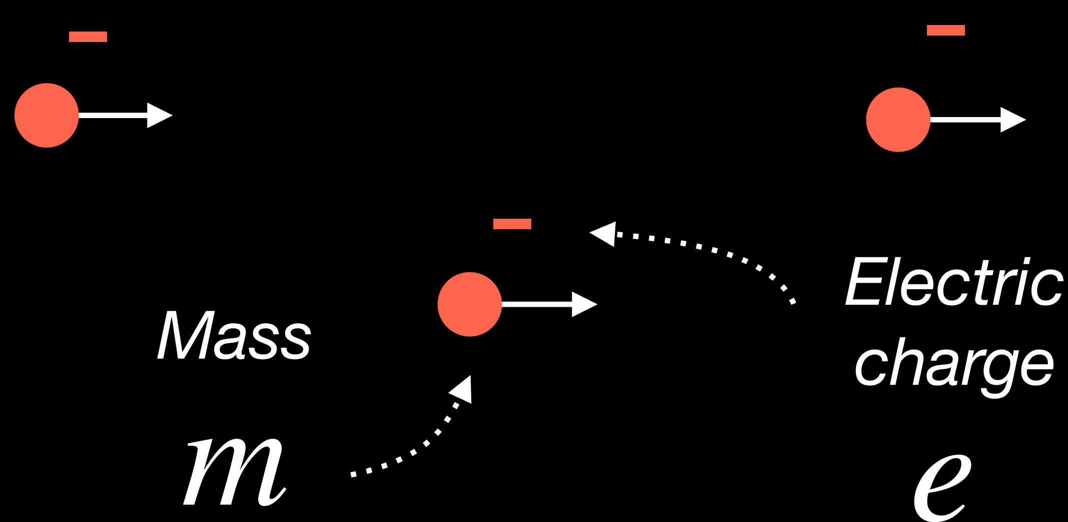

J. J. Thomson (1897):

Electricity is a stream of electrons

What is the nature of electricity?

What is the
nature of ~~electricity~~?

matter

Is matter continuous or discrete?

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A topic of “eternal” philosophical debate!

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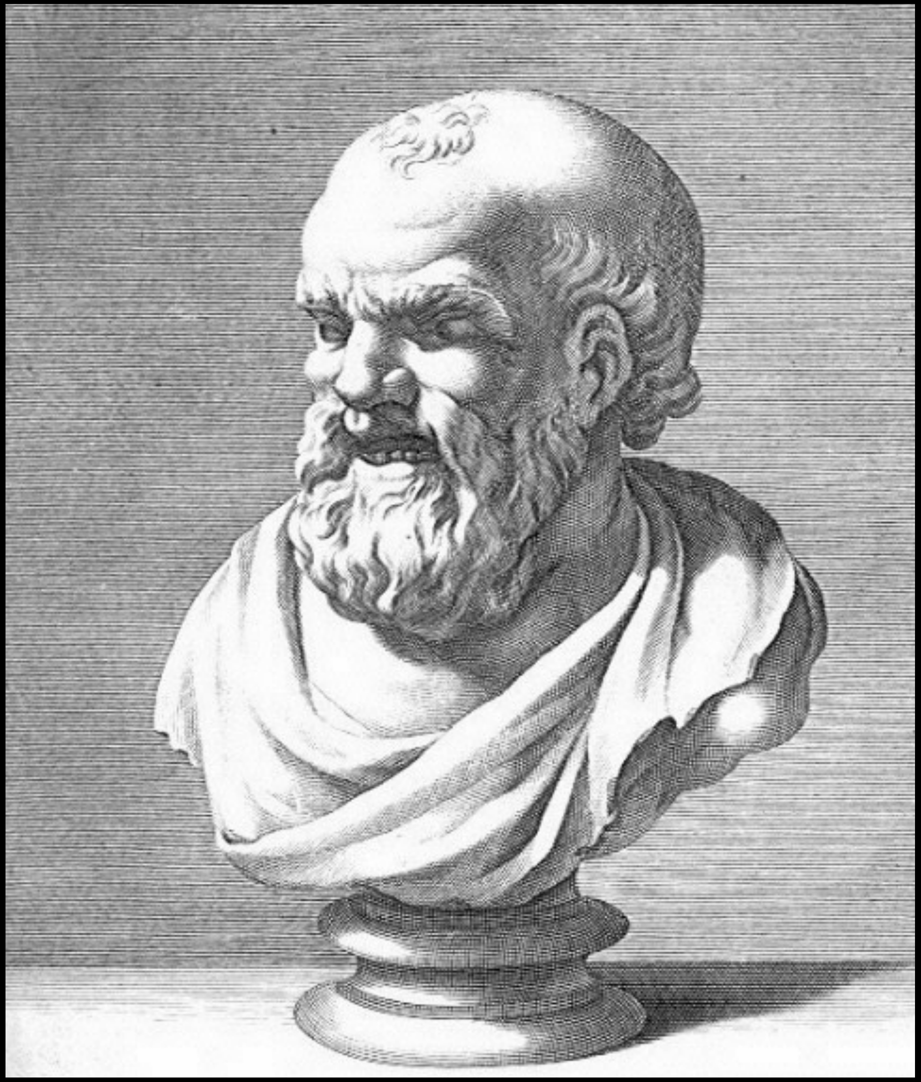

Democritus *(ca. 300 BC):*

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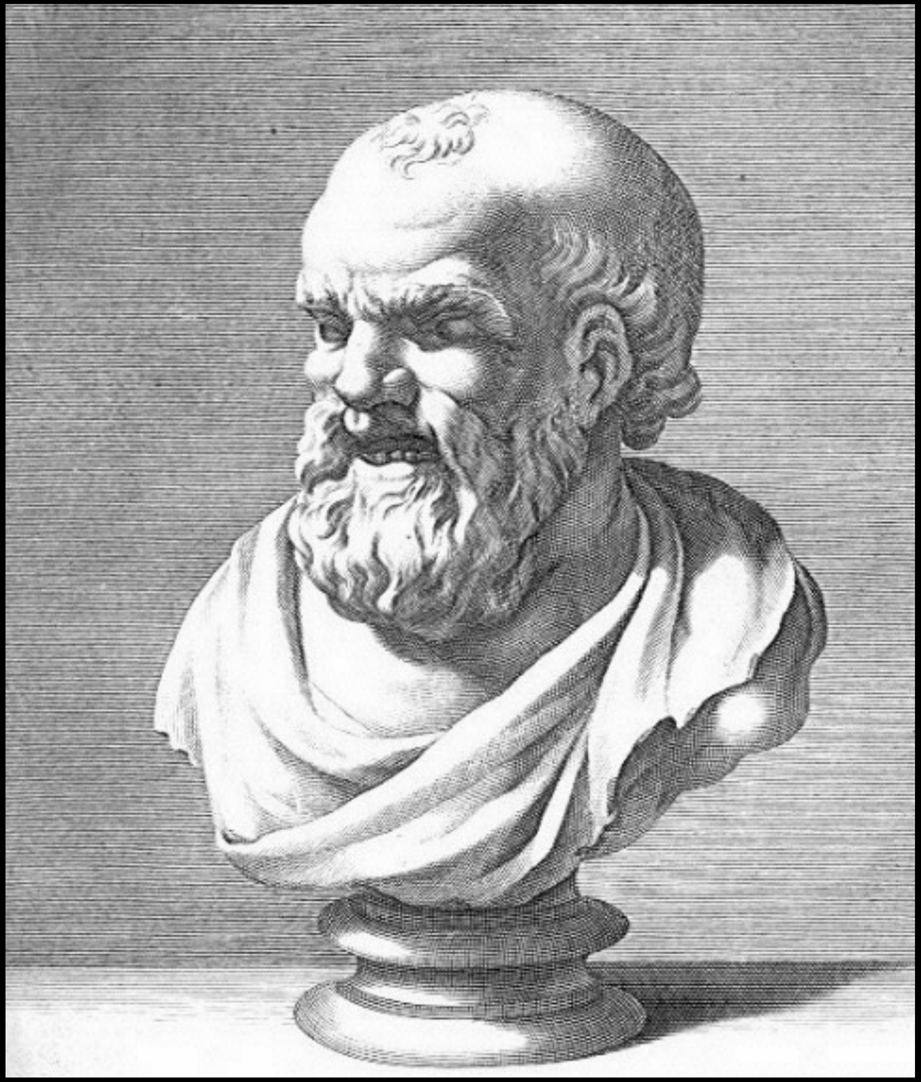

Democritus *(ca. 300 BC):*

"By convention there is sweetness,
by convention there is bitterness,
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in reality only atoms and the void."

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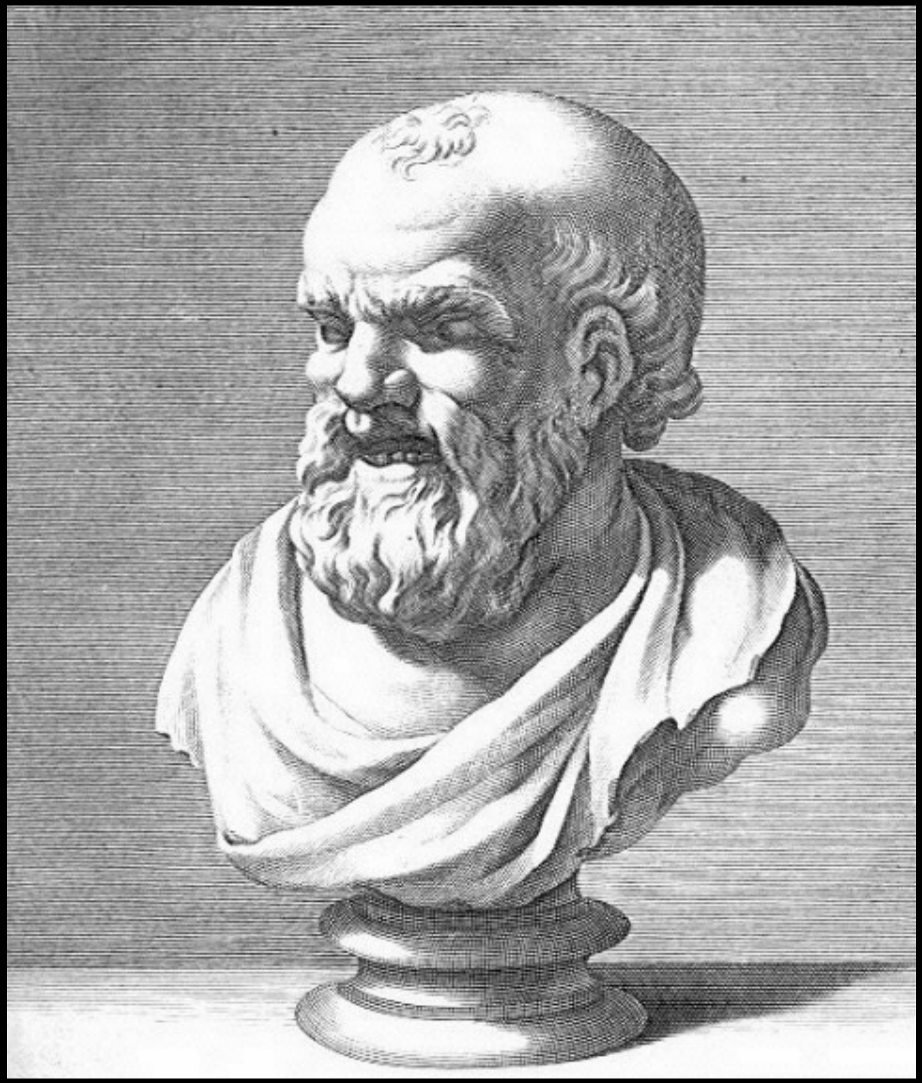

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"Bitterness is caused by small, angular,
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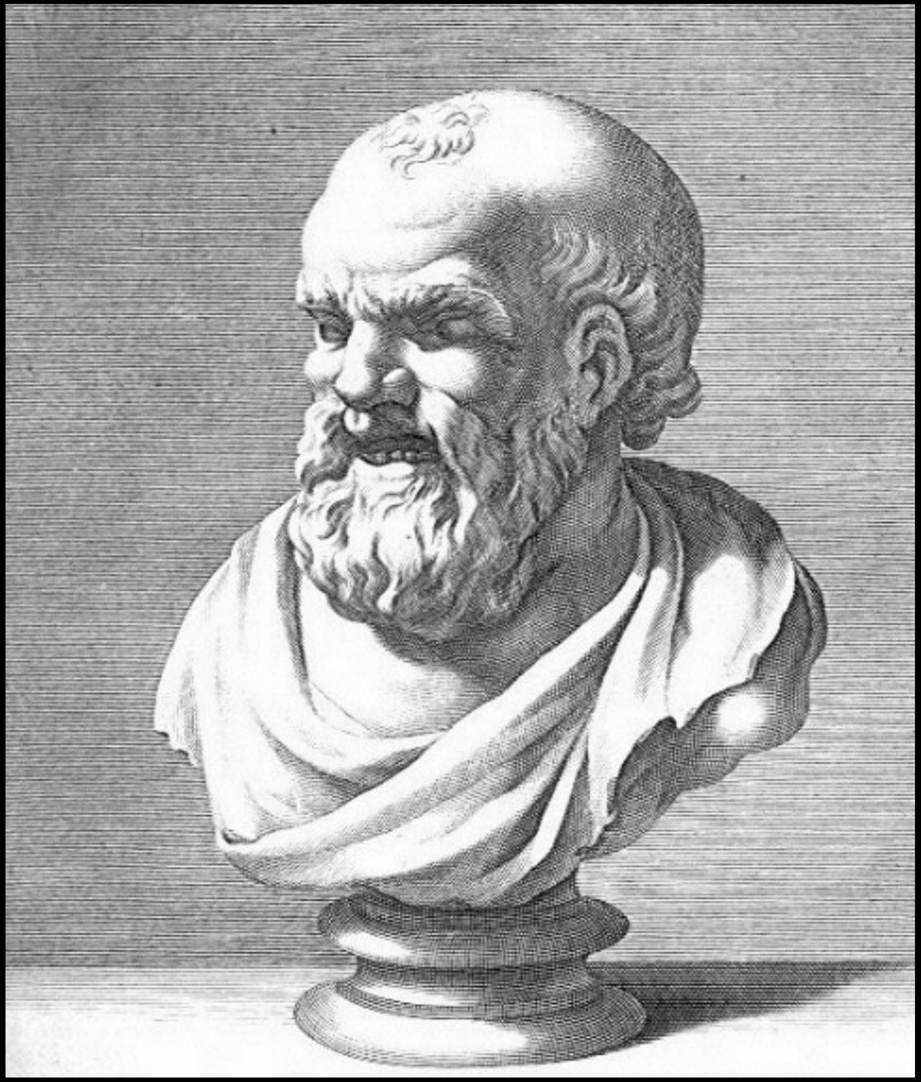

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"Bitterness is caused by small, angular, jagged atoms passing across the tongue."

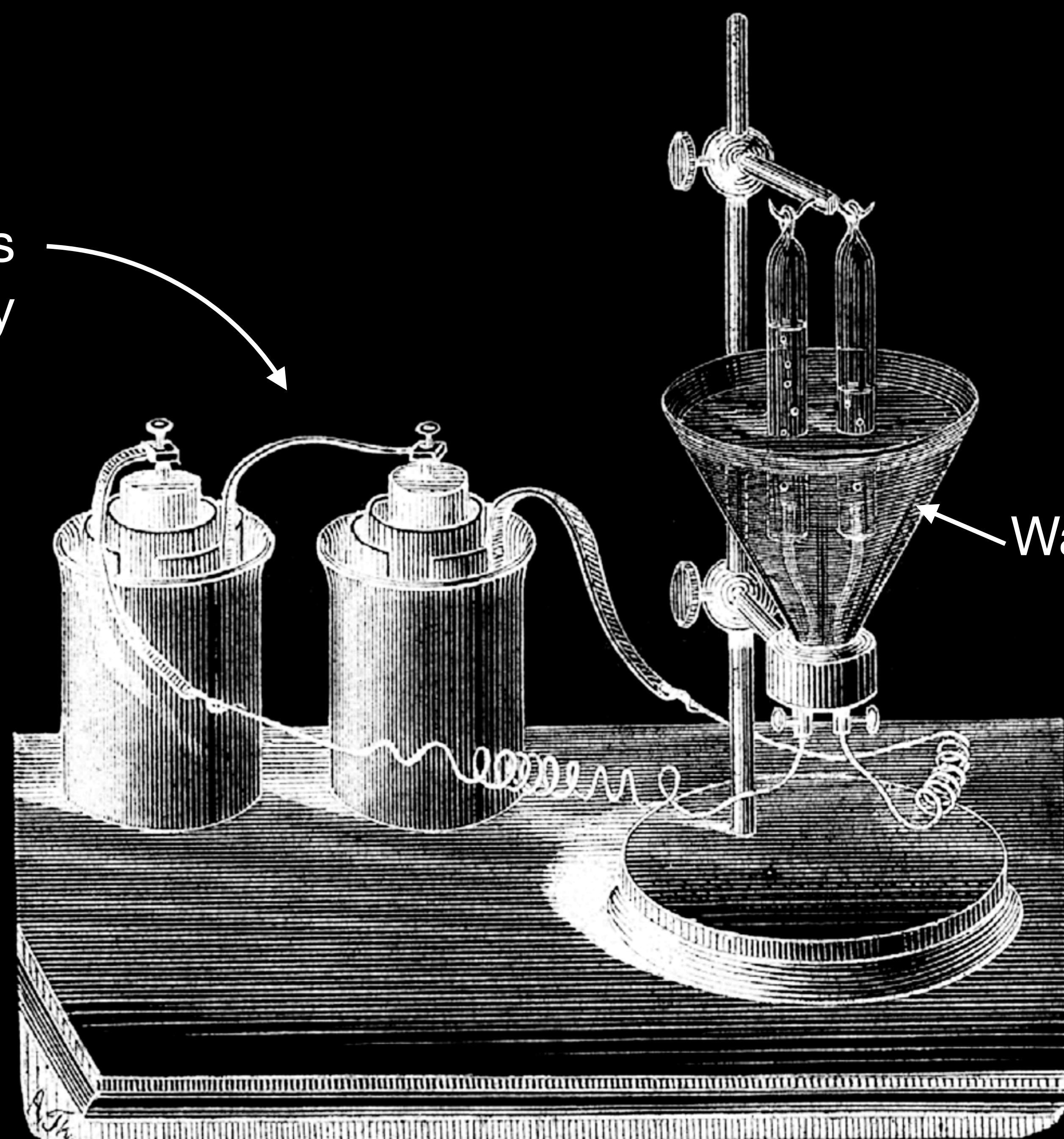
"Sweetness is caused by larger, smoother, more rounded atoms."

The first *real* hints: Chemistry

Splitting substances with electricity

Water → Hydrogen + Oxygen

Early 1800s



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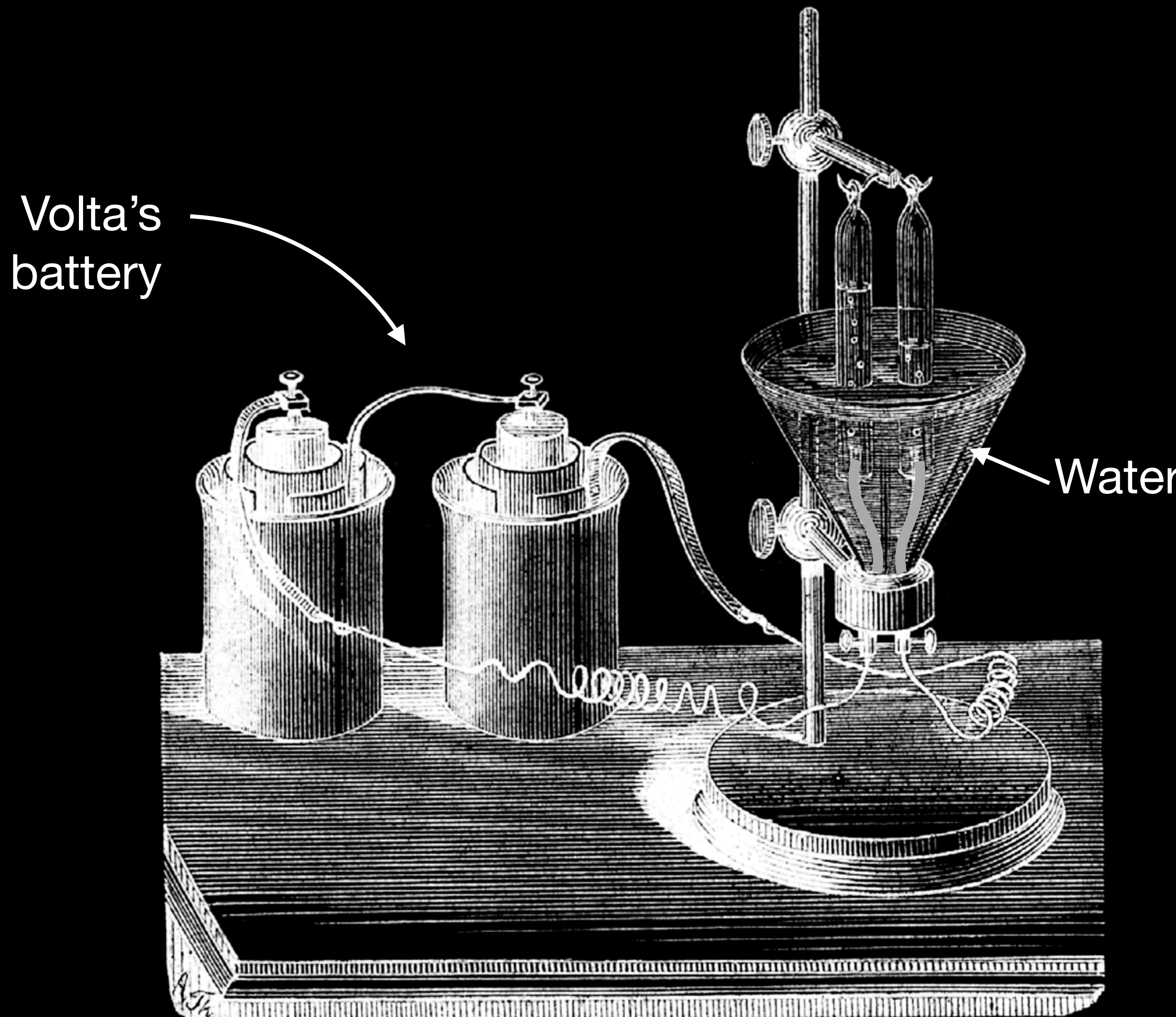

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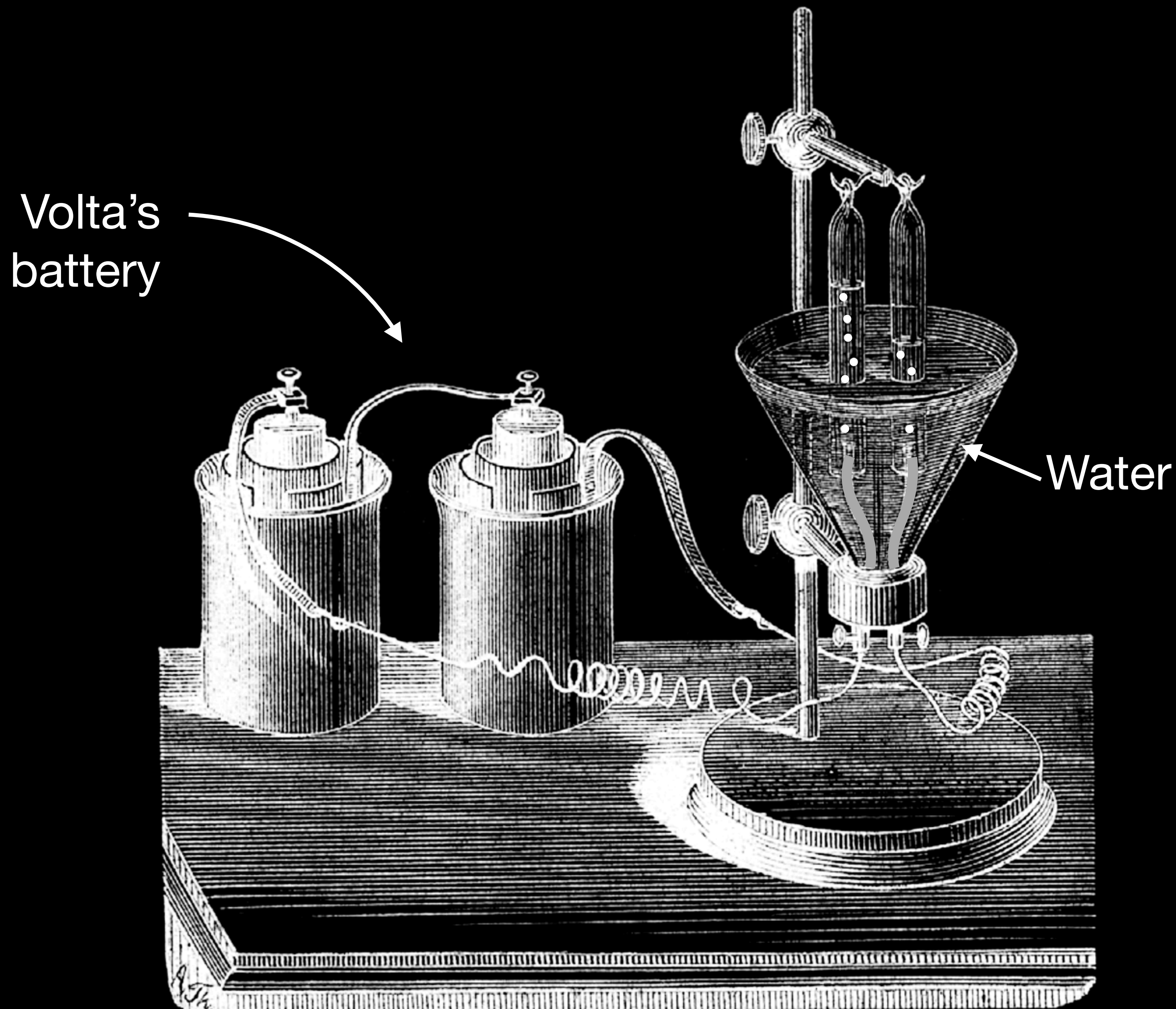

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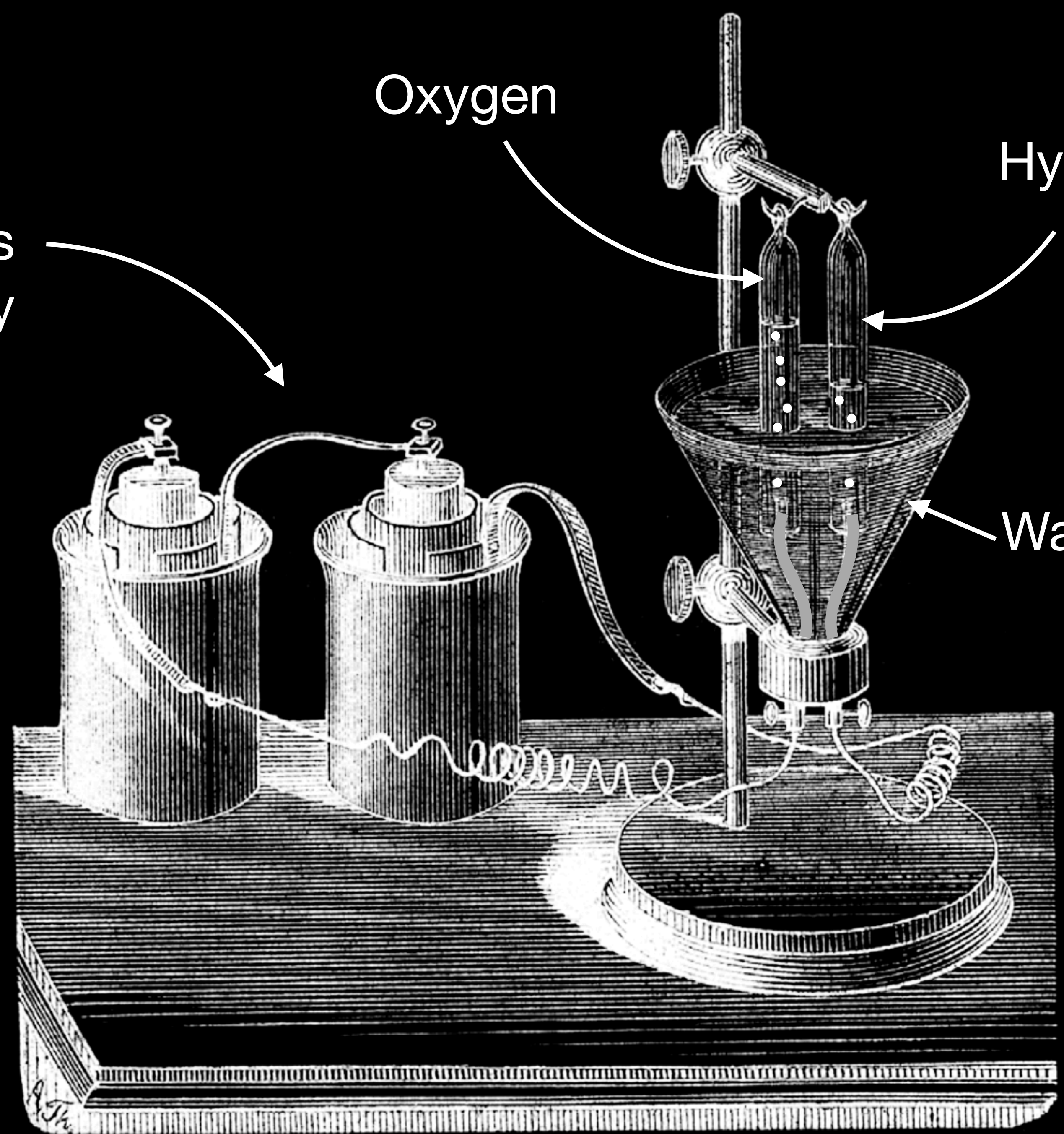

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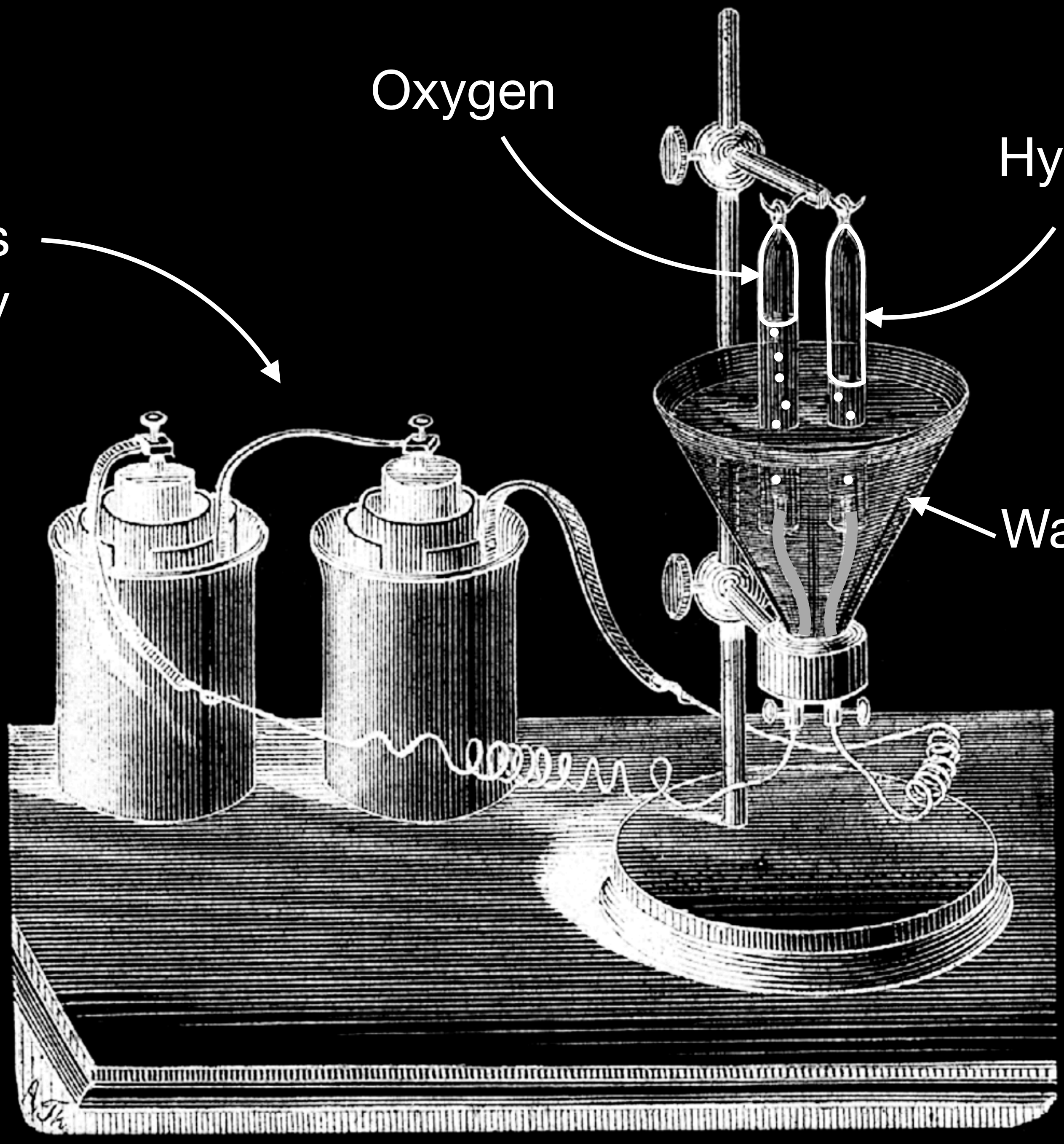

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The first *real* hints: Chemistry

Recombining substances

"When two measures of hydrogen and one of oxygen gas are mixed, and fired by the electric spark, the whole is converted into steam."

Hydrogen + Oxygen → Water

John Dalton

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John Dalton

Oxygen
133g

+

Carbon
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Carbon *100g* + **Oxygen** *133g* → **Carbon monoxide**

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John Dalton

		Oxygen *133g*	→	**Carbon monoxide**
	+			
Carbon *100g*				
	+	**Oxygen** *266g*		

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***"Law of multiple proportions"* (1804)**

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***"Law of multiple proportions"* (1804)**

Such ratios will always involve whole numbers!

Dalton’s atoms (1808)

“In all chemical investigations, all the changes we can produce consist in separating particles that are in a state of cohesion, and joining those that were previously at a distance.”

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1 atom of A + 2 atoms of B = 1 atom of D

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"Water is a binary compound of hydrogen and oxygen, and the relative weights of the two elementary atoms are as 1 : 7."

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1) Atoms are elementary

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2) As such, they only come in whole numbers

3) The masses of different atoms relate to each other as whole numbers

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"Water is a binary compound of hydrogen and oxygen, and the relative weights of the two elementary atoms are as 1 : 7."

Wrong! It's 1:16!

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Dalton’s atoms (1808)

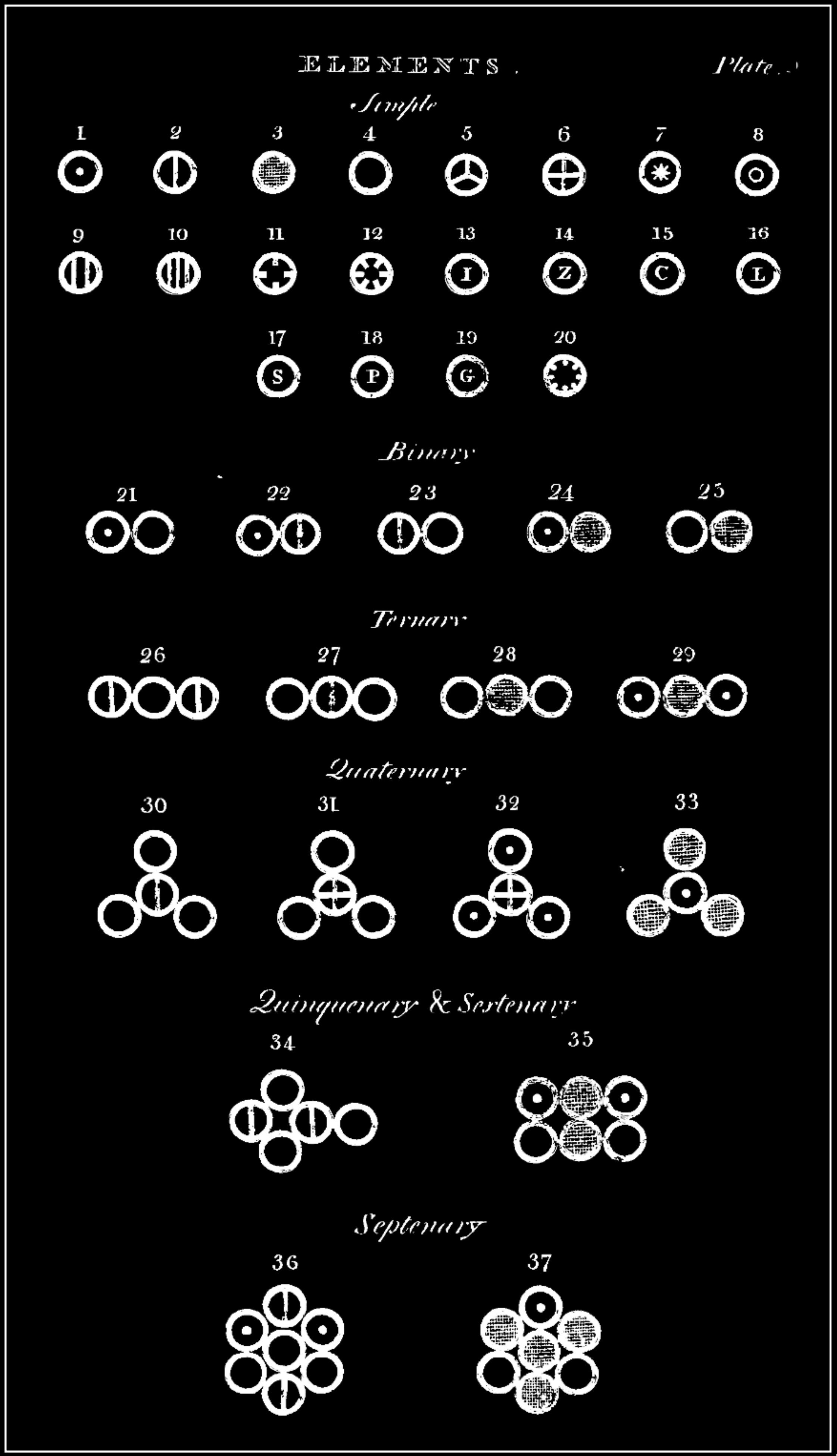

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Table of relative atomic weights:

Fig.			Fig.		
1	Hydrog. its rel. weight	1	11	Strontites	46
2	Azote	5	12	Barytes	68
3	Carbone or charcoal...	5	13	Iron	38
4	Oxygen	7	14	Zinc	56
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6	Sulphur	13	16	Lead	95
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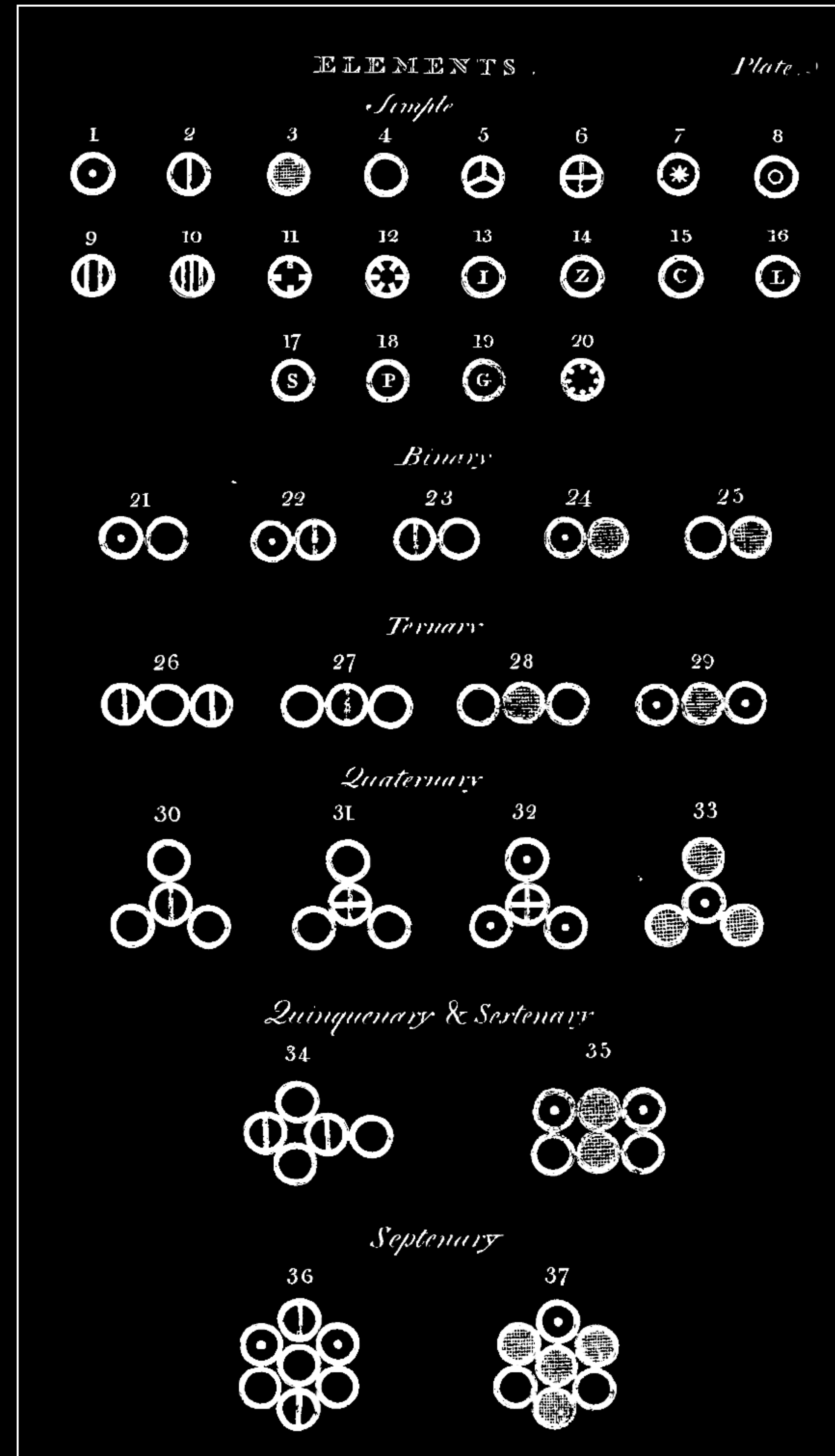

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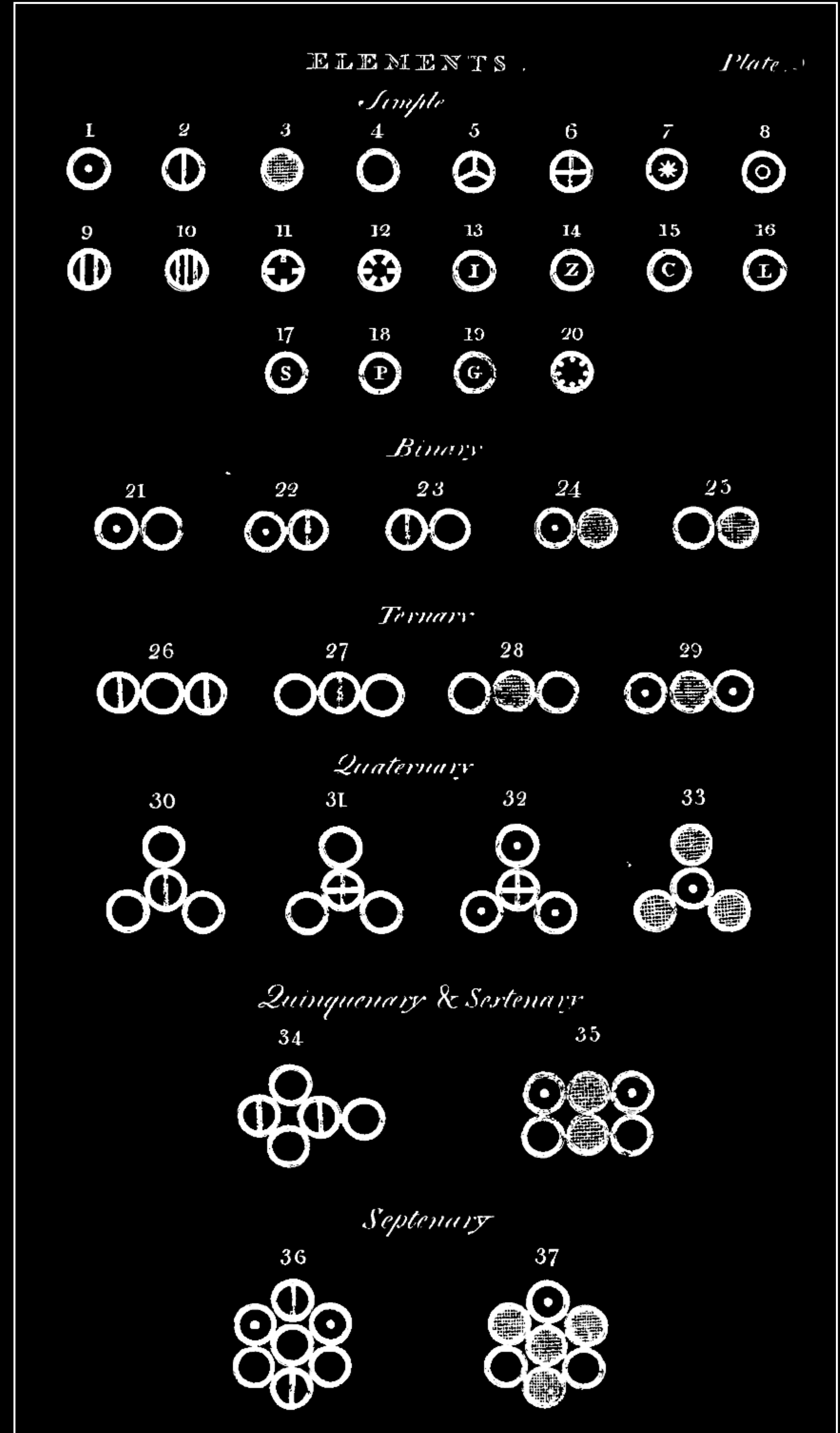
On the nature of atoms:



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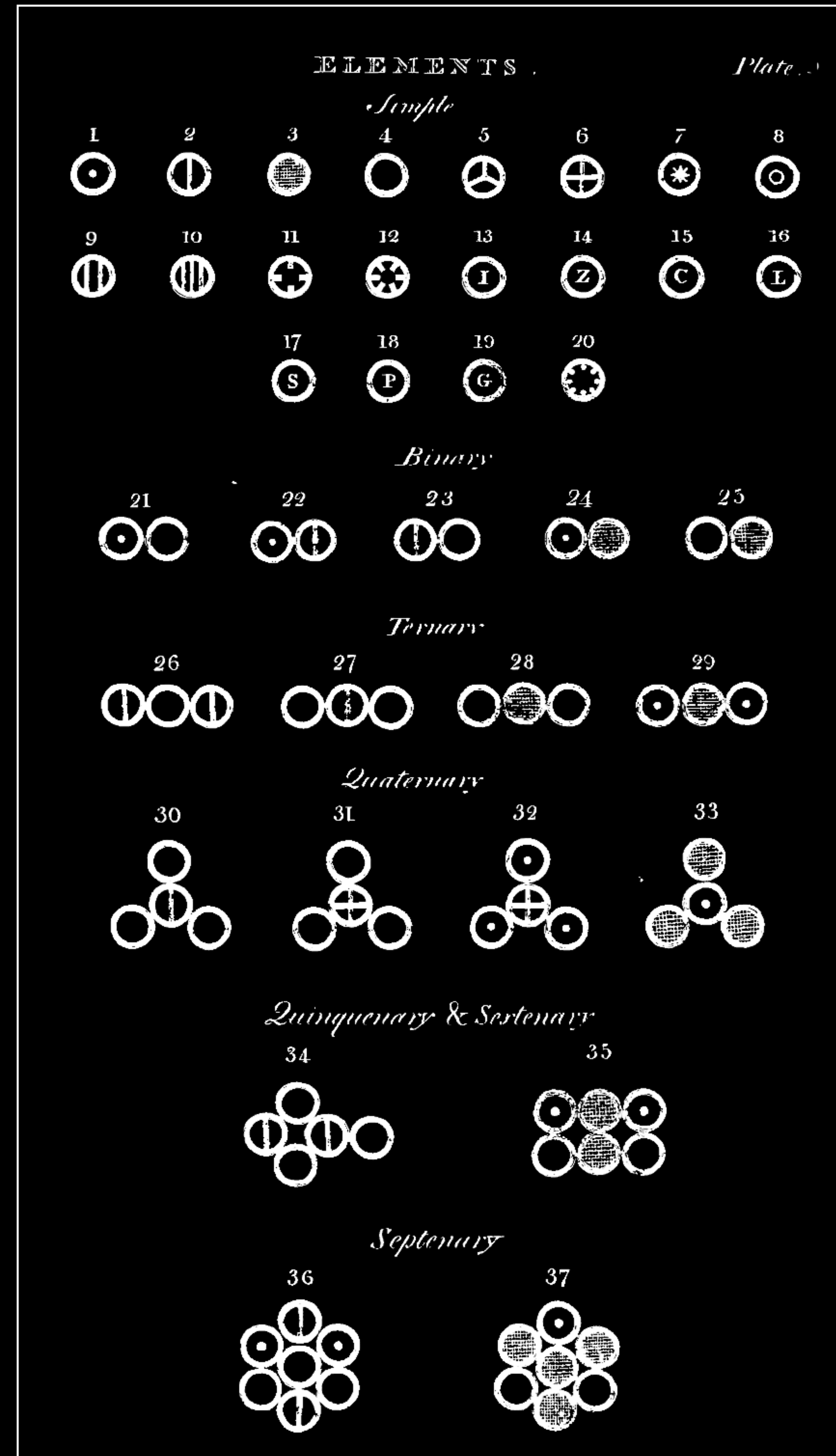

On the nature of atoms:

"The atoms of such bodies are conceived at present to be simple."

Dalton's atoms (1808)

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Some are close, but most are wrong!

On the nature of atoms:

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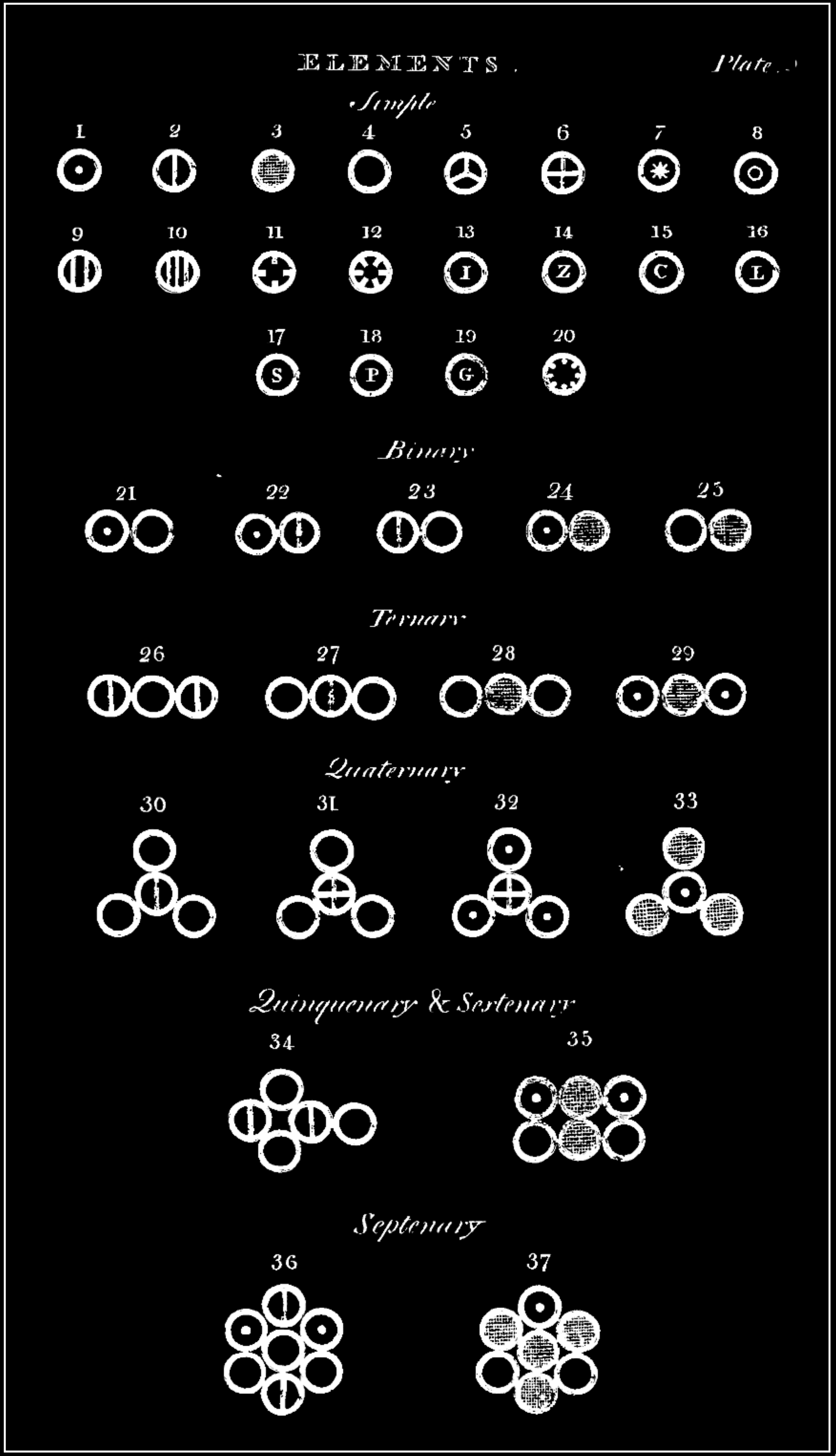
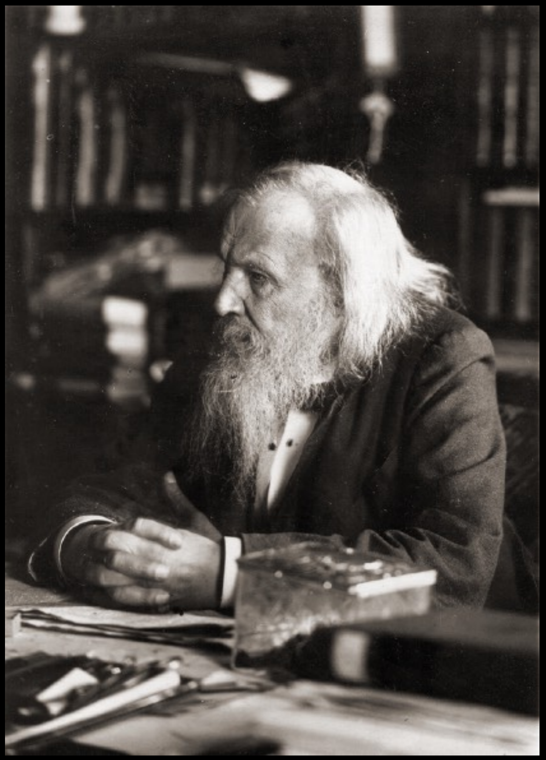


Yet more regularity

1863: 56 chemical elements *(ca. 1 new discovery per year)*

Is there any order in this chaos?



Dmitri Mendeleev

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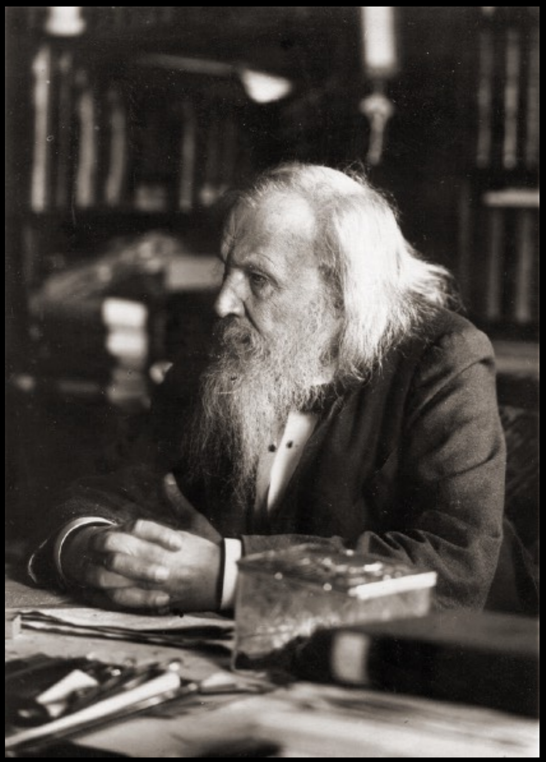

Dmitri Mendeleev

Reihen	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Mendeleev's table *(1871)*

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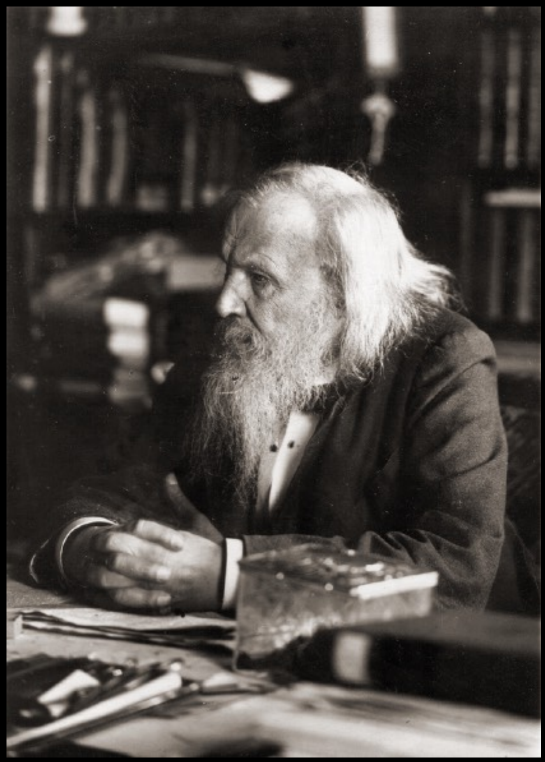

Dmitri Mendeleev

Eight groups of chemically similar elements

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

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(1871)

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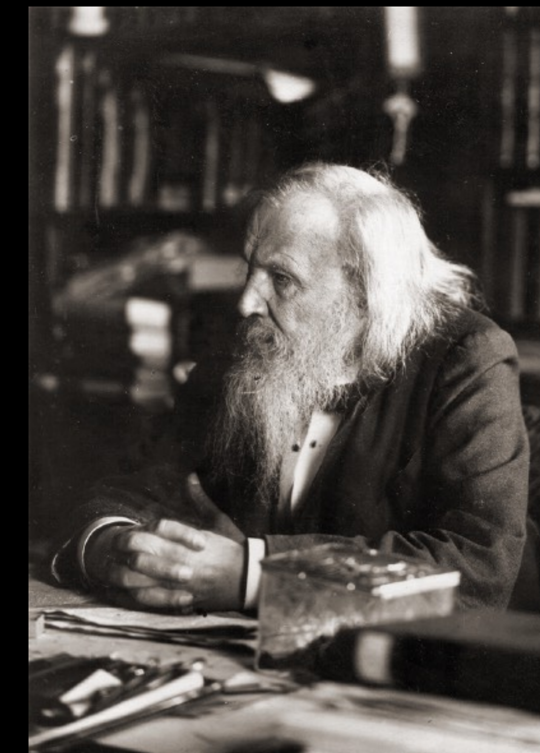

Dmitri Mendeleev

Eight groups of chemically similar elements

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
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5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
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12	—	—	—	Th=231	—	U=240	—	— — — —

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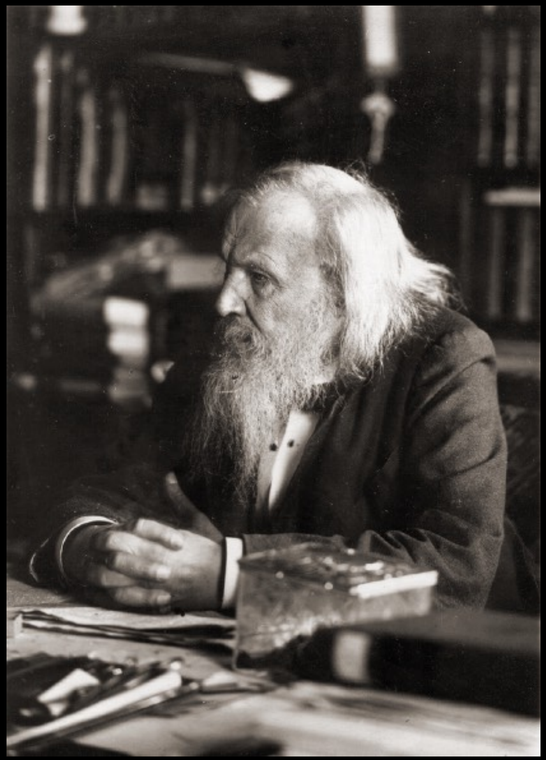

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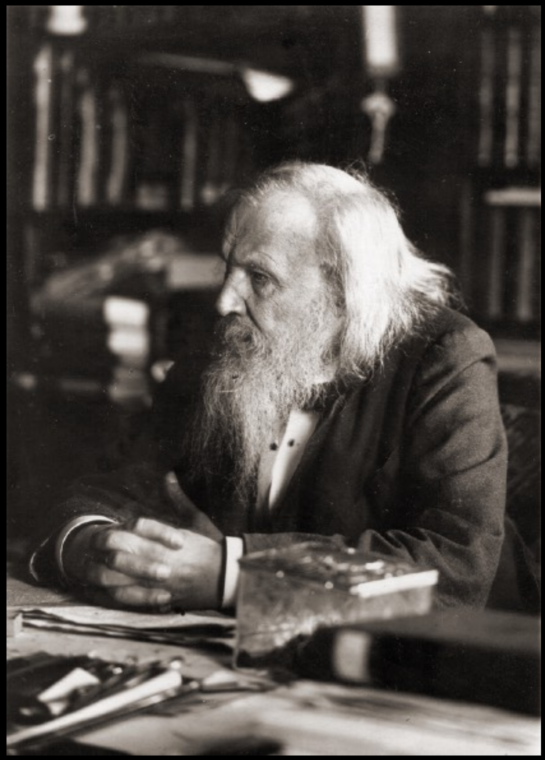

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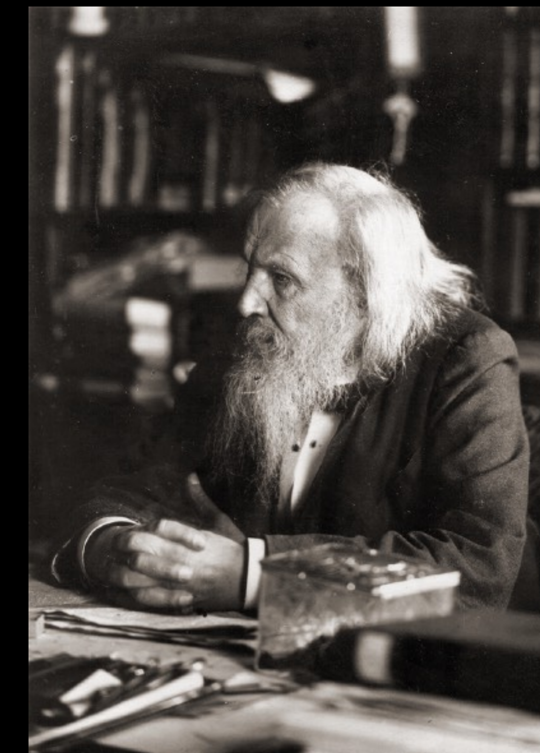

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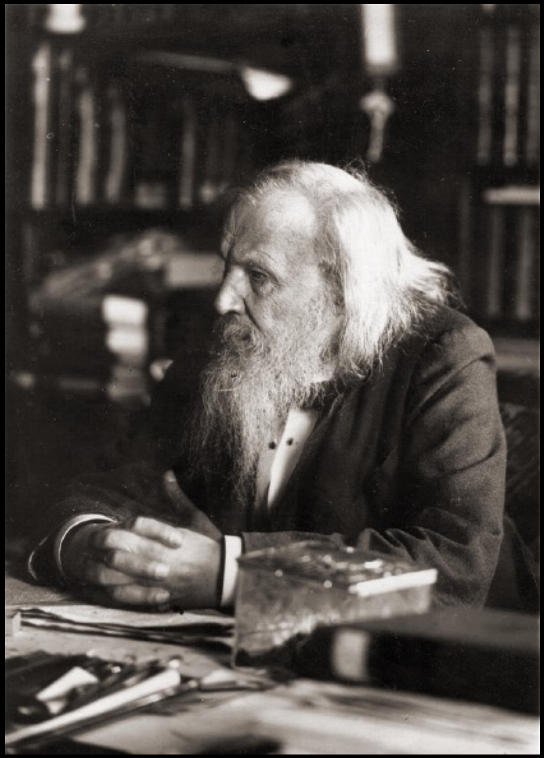

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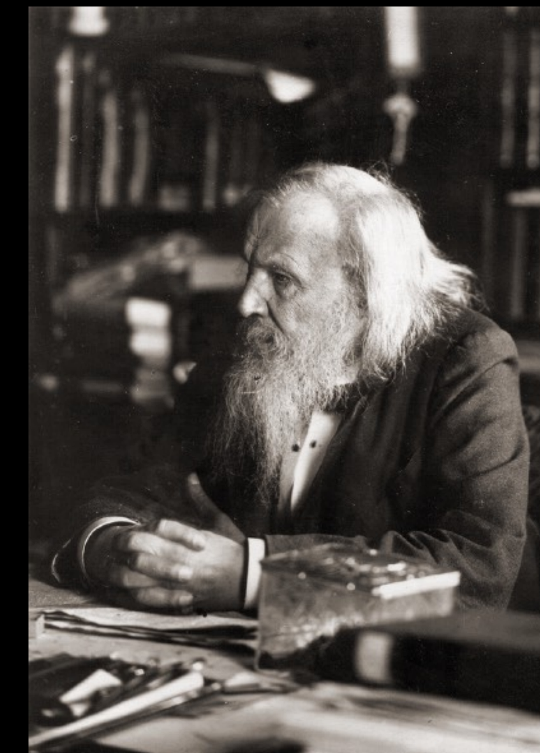

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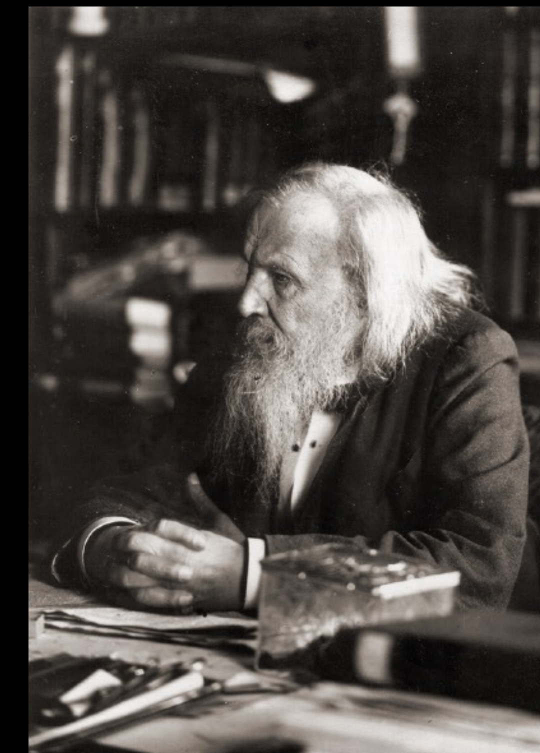

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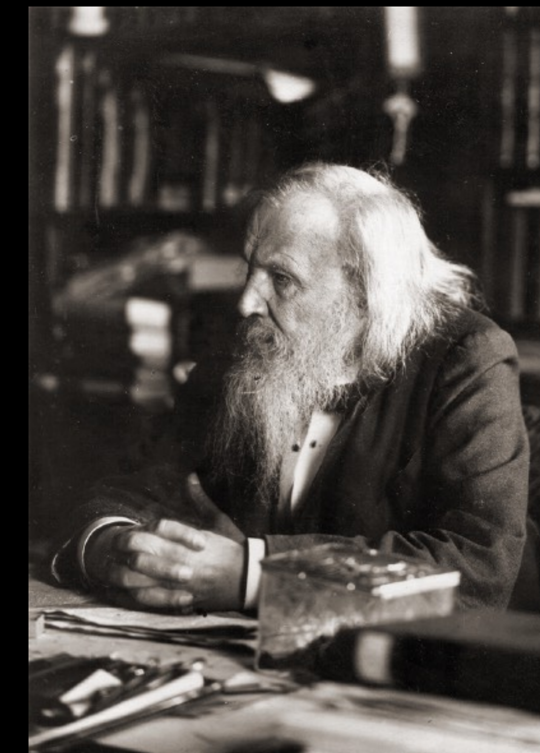

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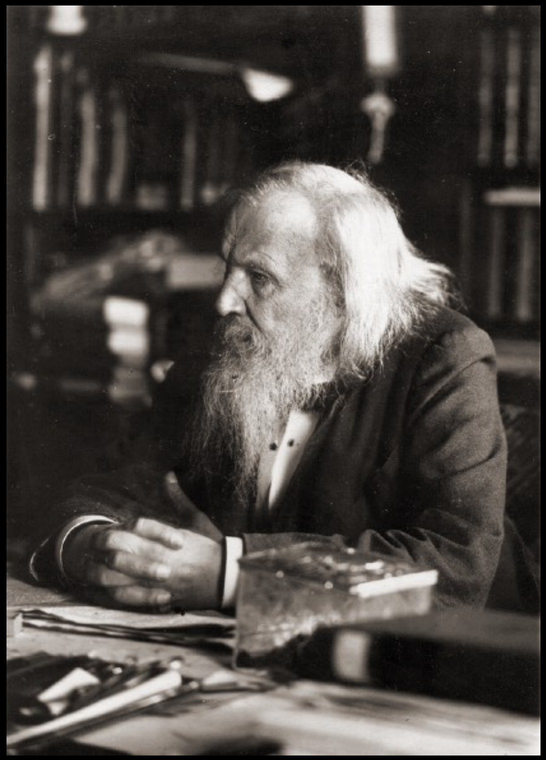

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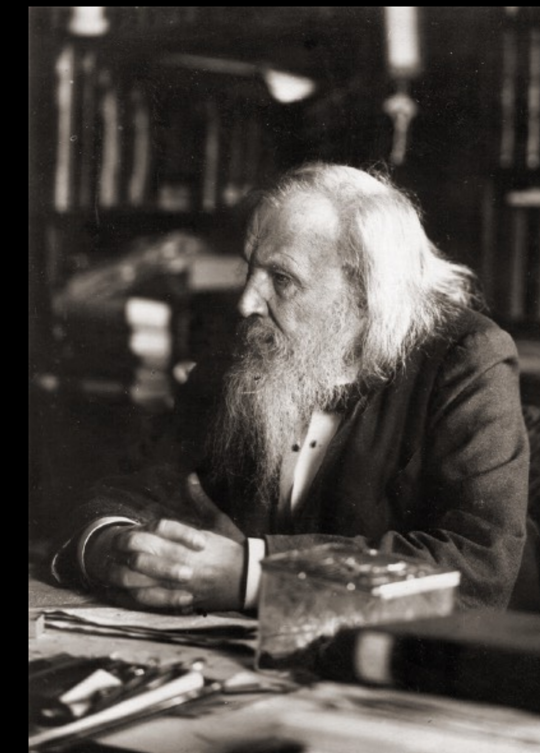

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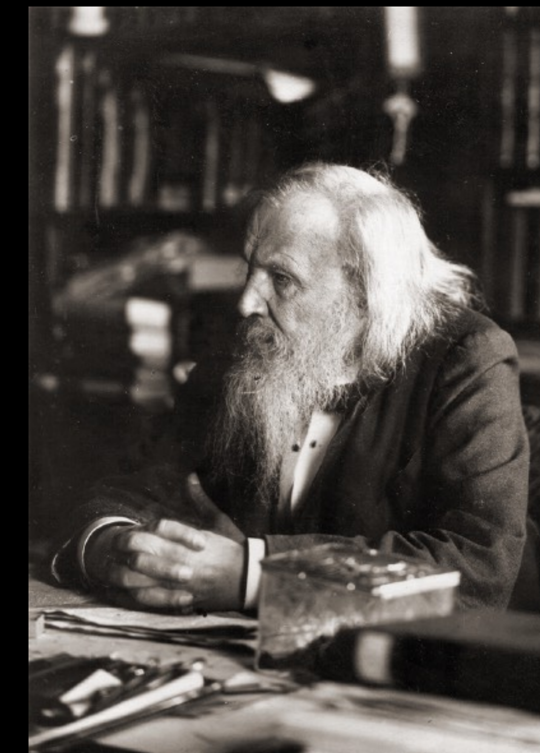

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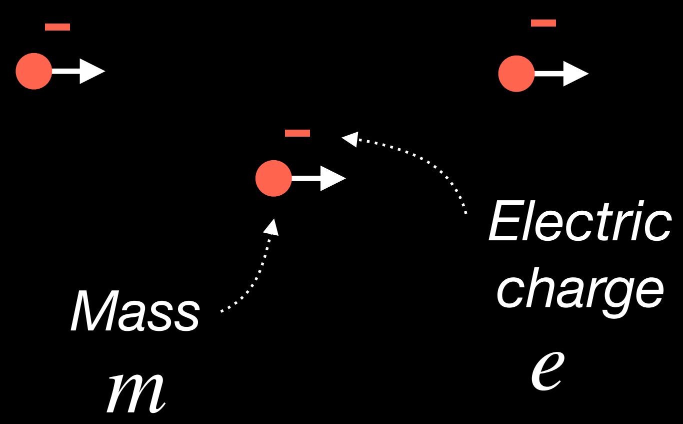
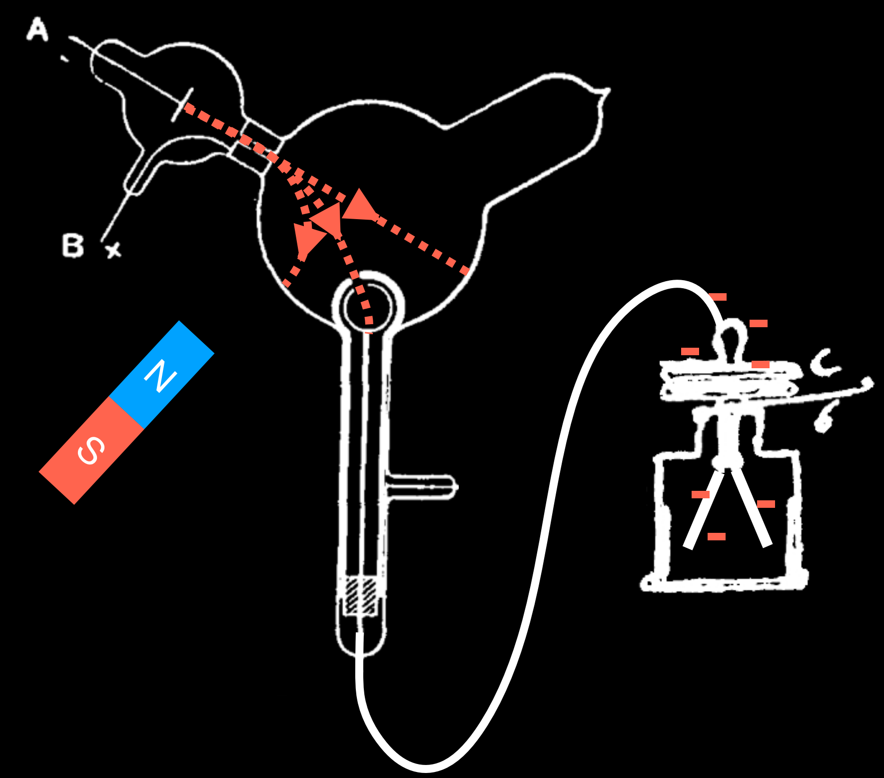
Back to Thomson in 1897

A stream of electrons



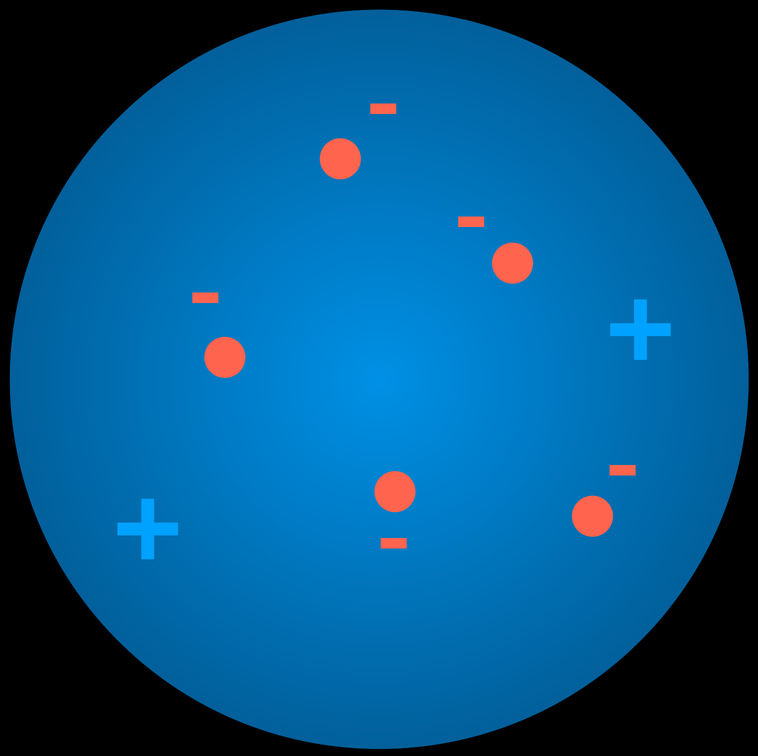


“Thus on this view, we have in the cathode rays matter in a new state, a state in which the subdivision of matter is carried very much further than in the ordinary gaseous state.”

Thomson's view of the atom (1904)

Normal matter is electrically neutral

→ Atoms are electrically neutral



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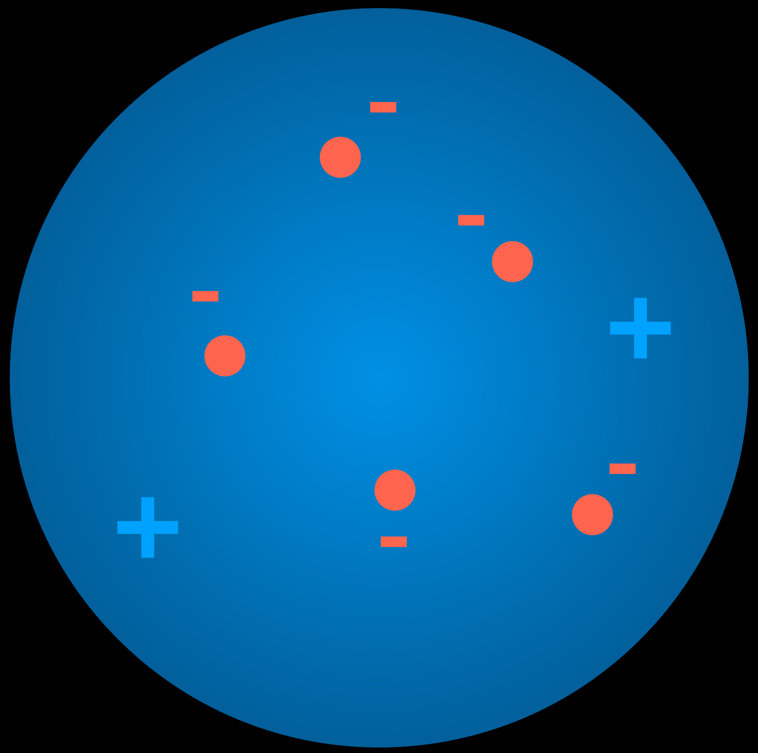

"We suppose that the atom consists of a number of corpuscles moving about in a sphere of uniform positive electrification."

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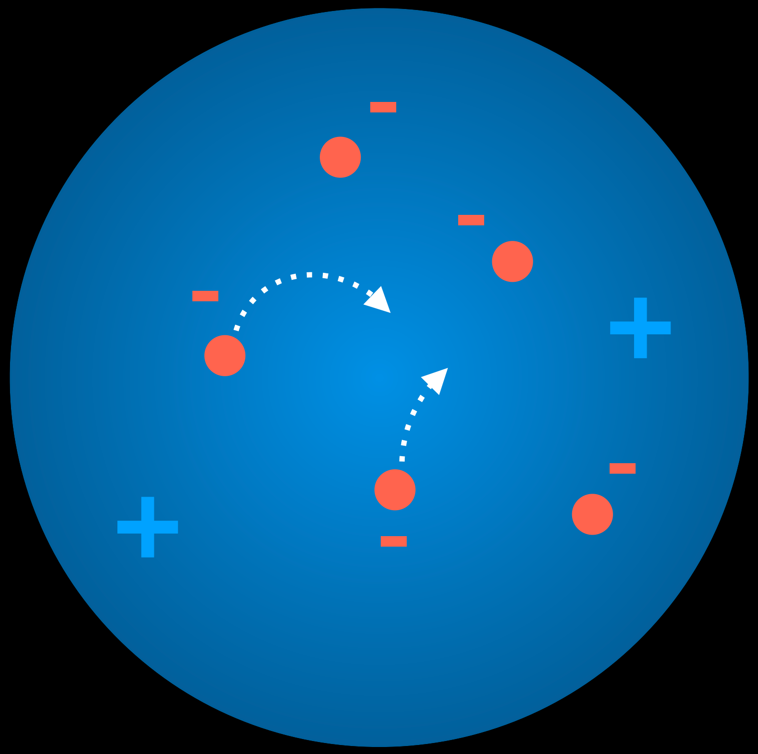

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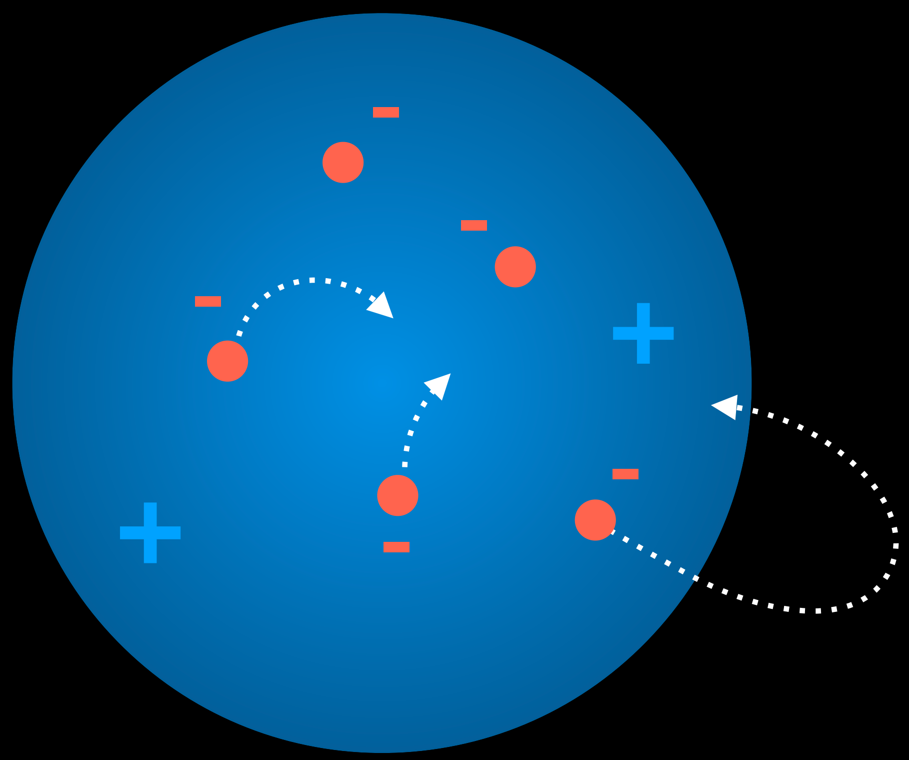
→ Atoms are electrically neutral



"We suppose that the atom consists of a number of corpuscles moving about in a sphere of uniform positive electrification."

Thomson's view of the atom (1904)

"What properties would this structure confer upon the atom?"

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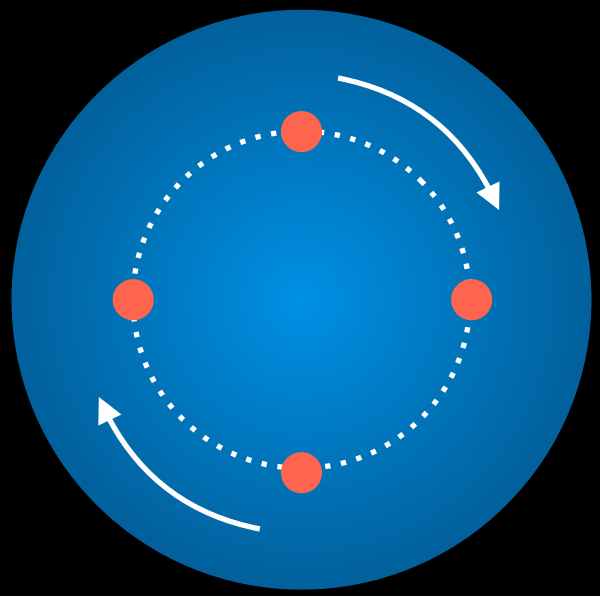

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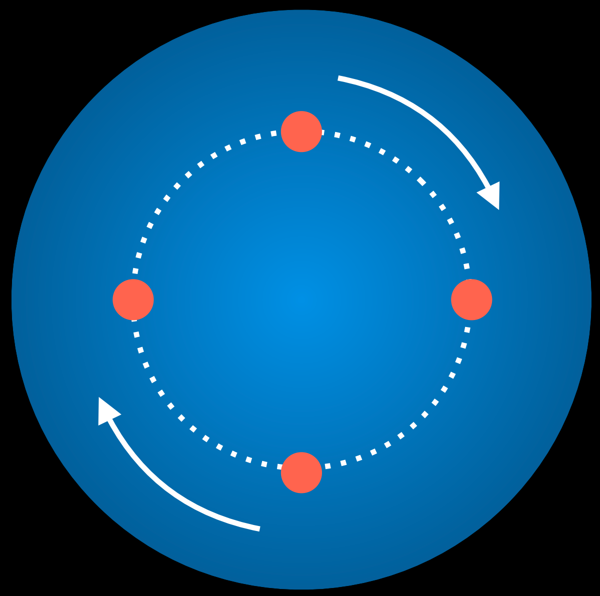

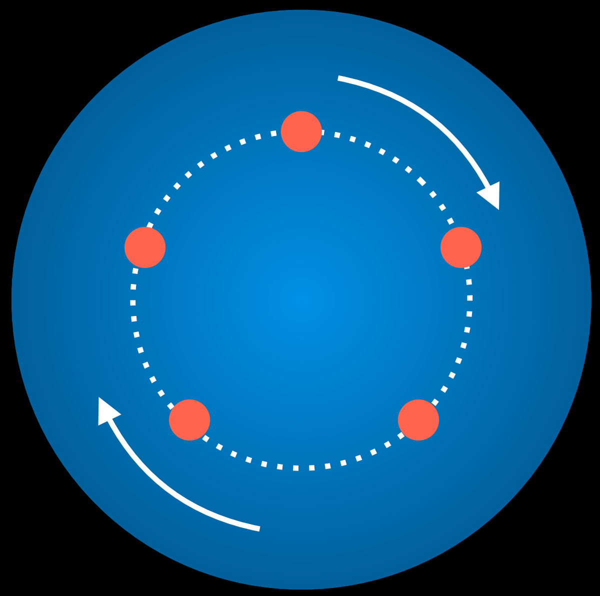

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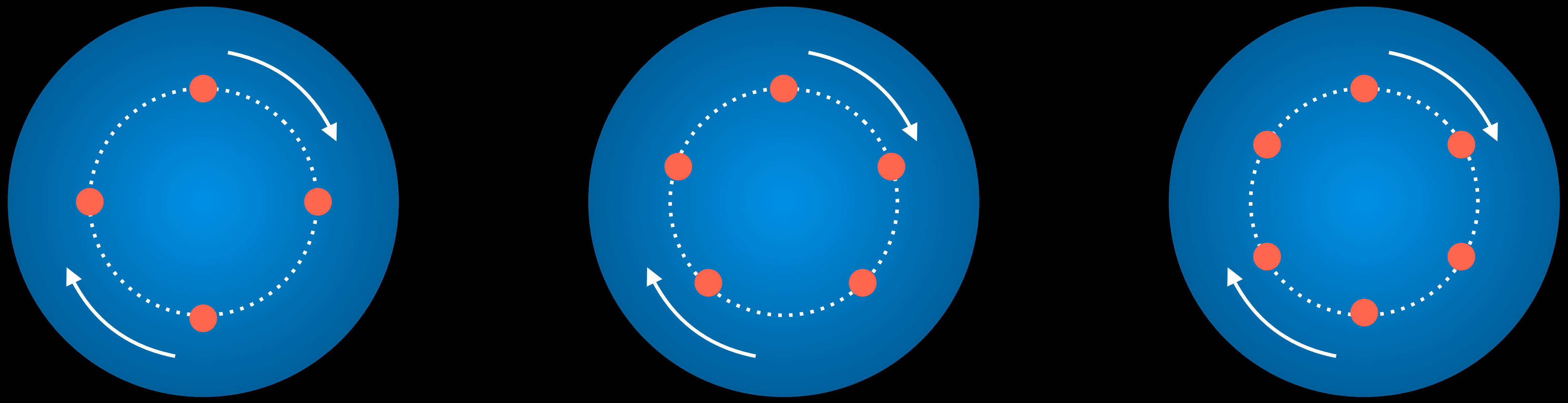

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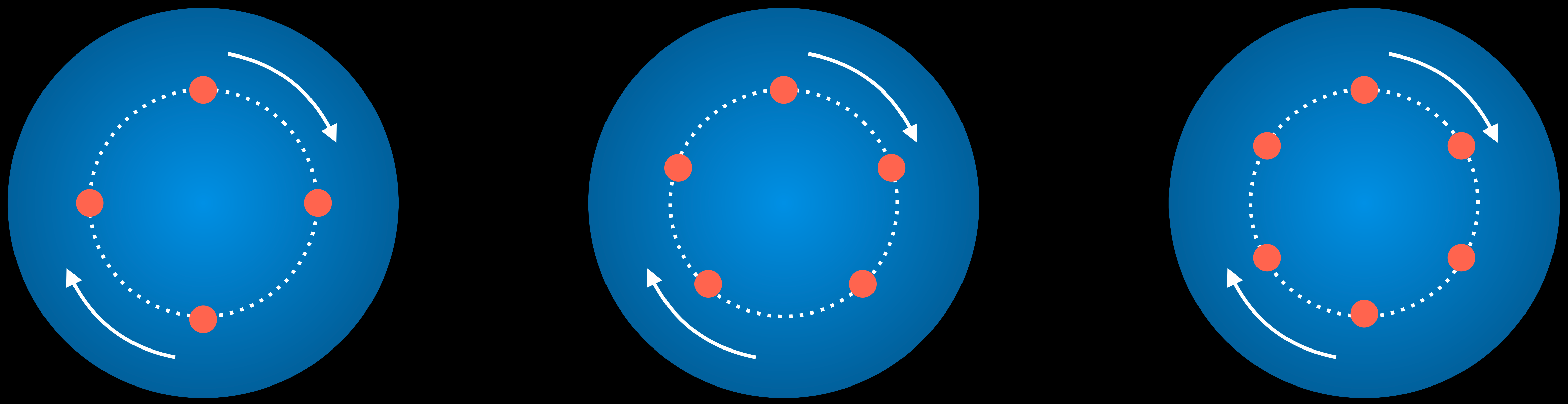

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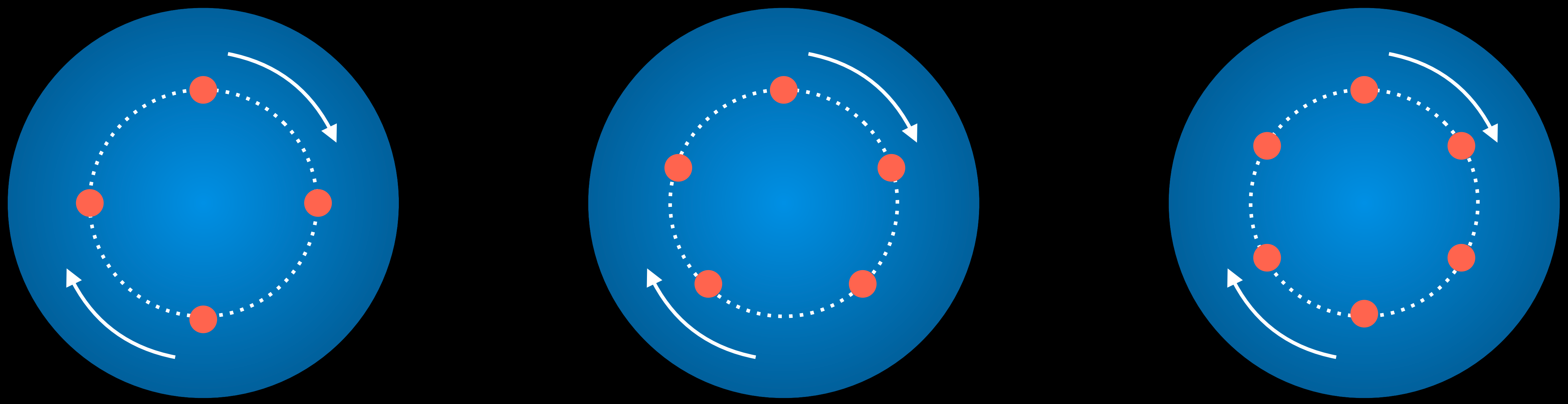

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"It can be made stable by placing inside it an appropriate number of corpuscles."

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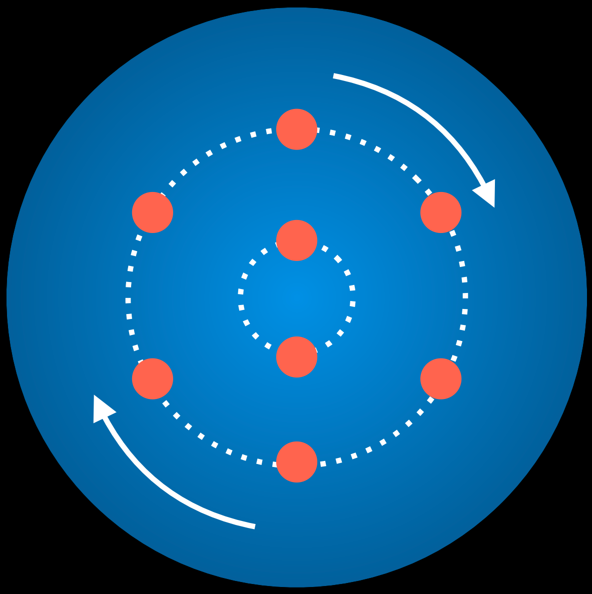

"Shells"

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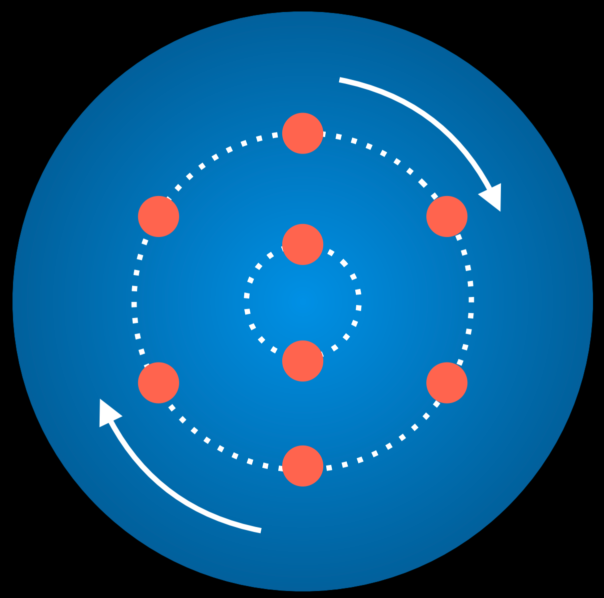

"Shells"

What would be the chemical properties of such atoms?

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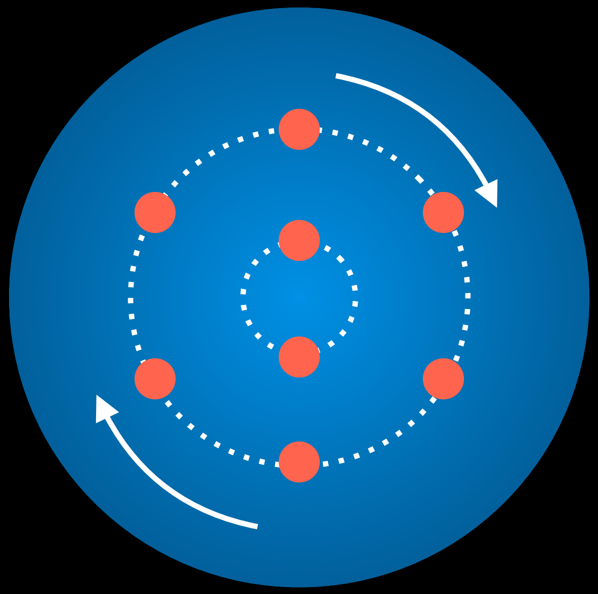


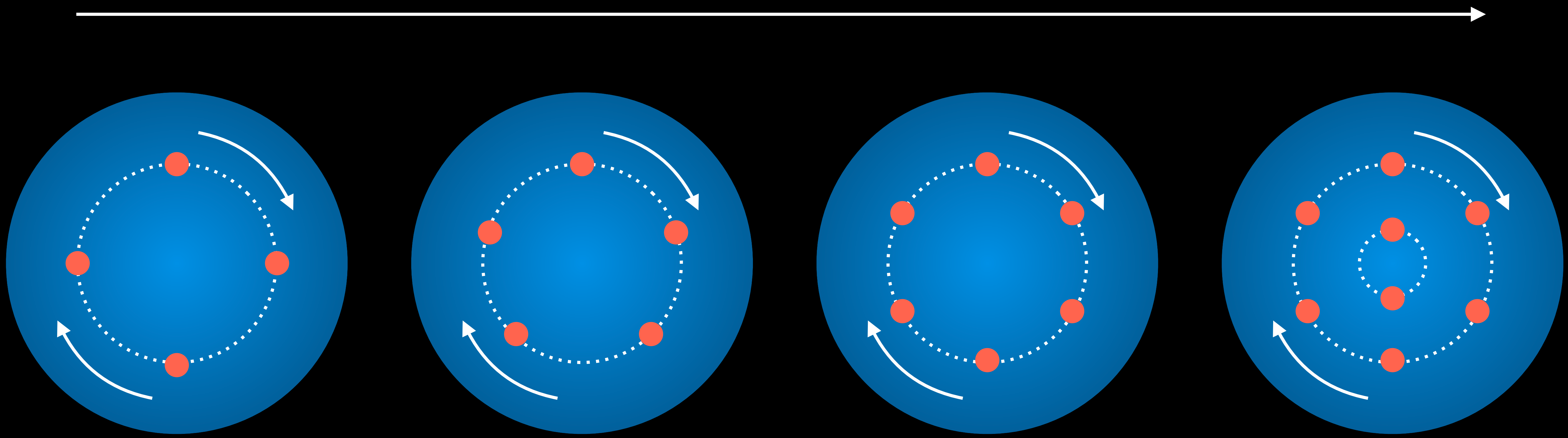
"Shells"

What would be the chemical properties of such atoms?

Can the laws of mechanics and electricity explain chemistry?

Thomson's view of the atom (1904)

Adding more and more corpuscles: heavier atoms *(in discrete jumps!)*



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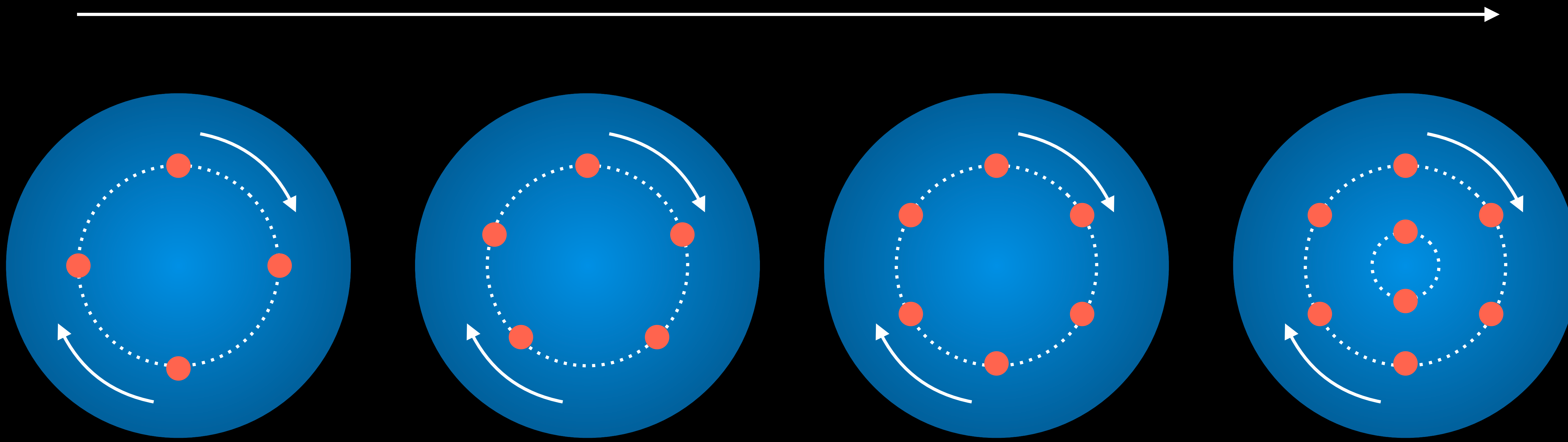


This sequence of properties is very like that observed in the case of the atoms of the elements.

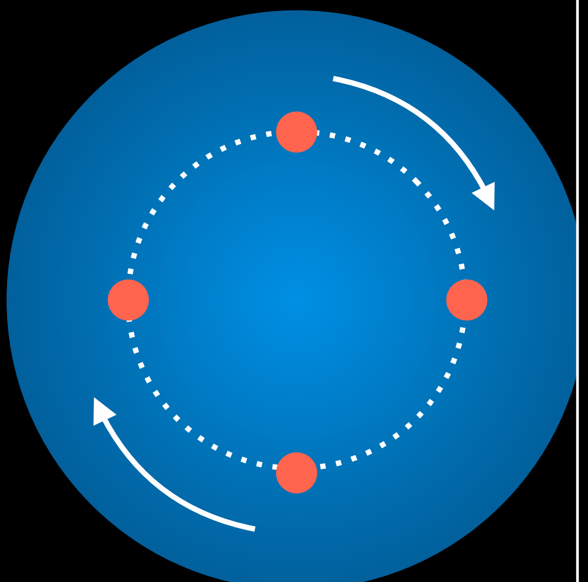
Thus we have the series of elements :

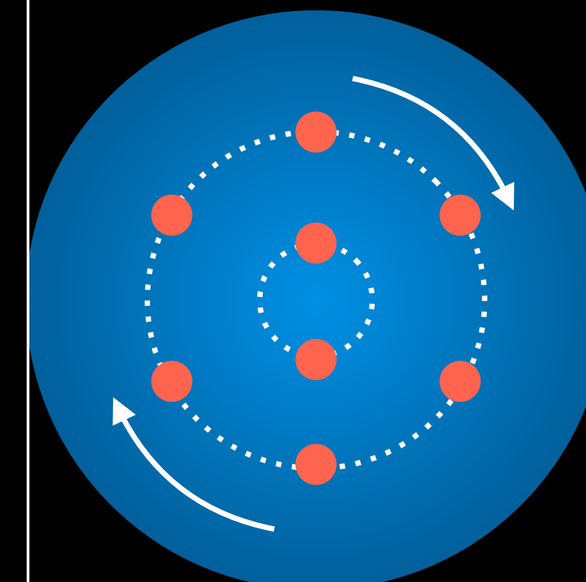
He	Li	Be	B	C	N	O	F	Ne.
Ne	Na	Mg	Al	Si	P	S	Cl	Arg.

The first and last element in each of these series has no valency, the second is a monovalent electropositive element, the last but one is a monovalent electronegative element, the third is a divalent electropositive element, the last but two a divalent electronegative element, and so on.

Thomson’s view of the atom (1904)

Adding … *jumps!)*





“Plum Pudding model”

Electrons are like raisins in a cake!

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How to look inside the atom?

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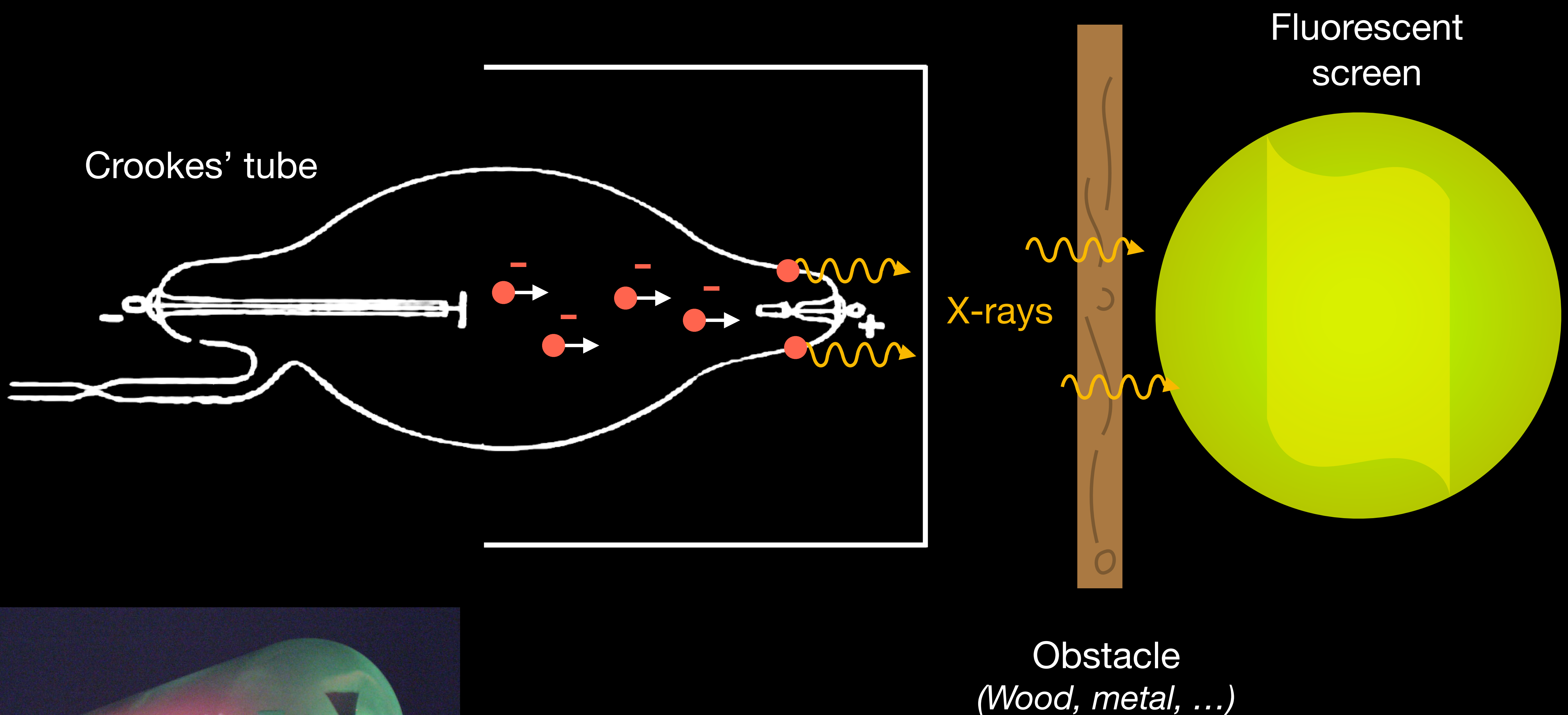
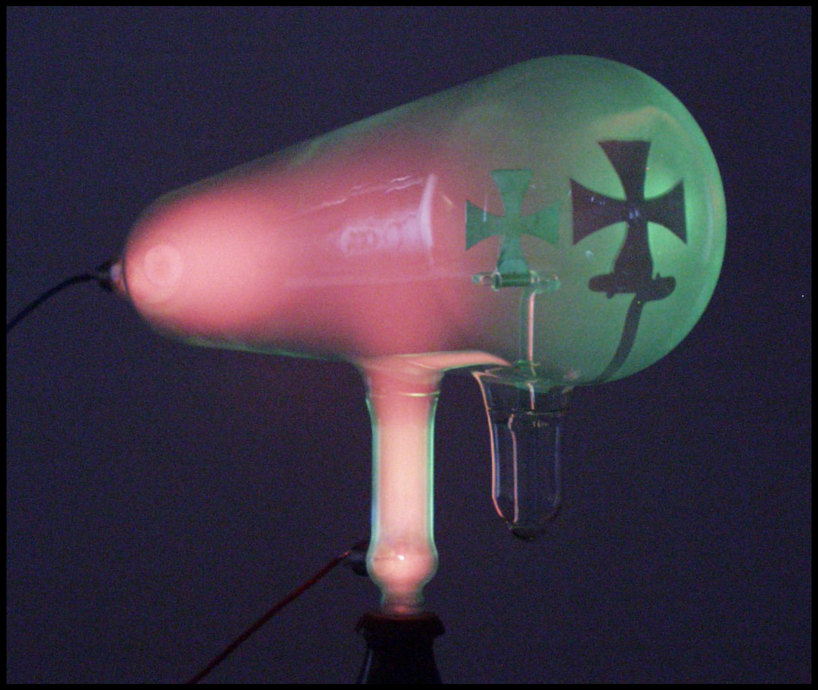
Back ten years to Röntgen and his X-rays …

Röntgen's big discovery (1895)

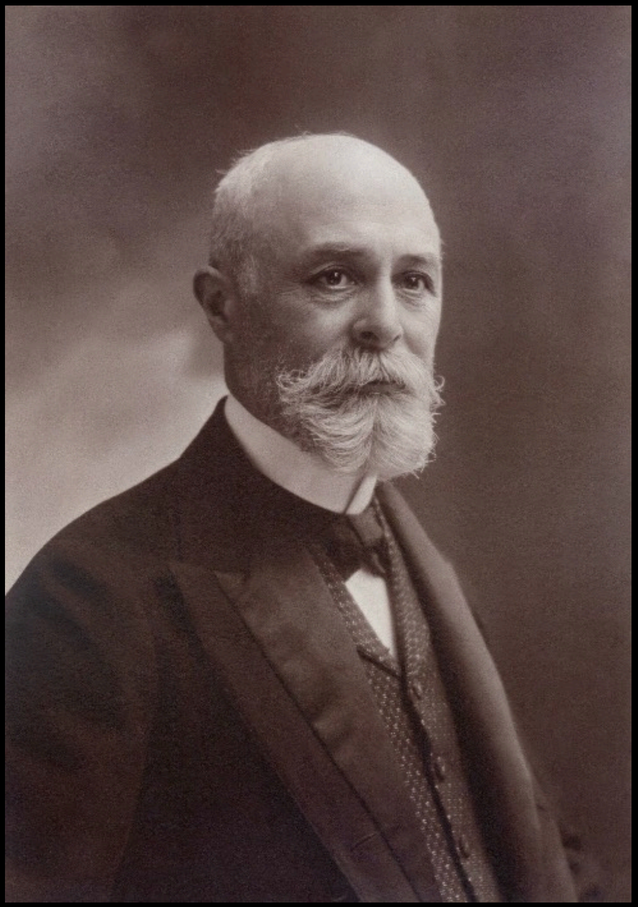




Used widely-available equipment

→ *surge of interest from other scientists*

Henri Becquerel



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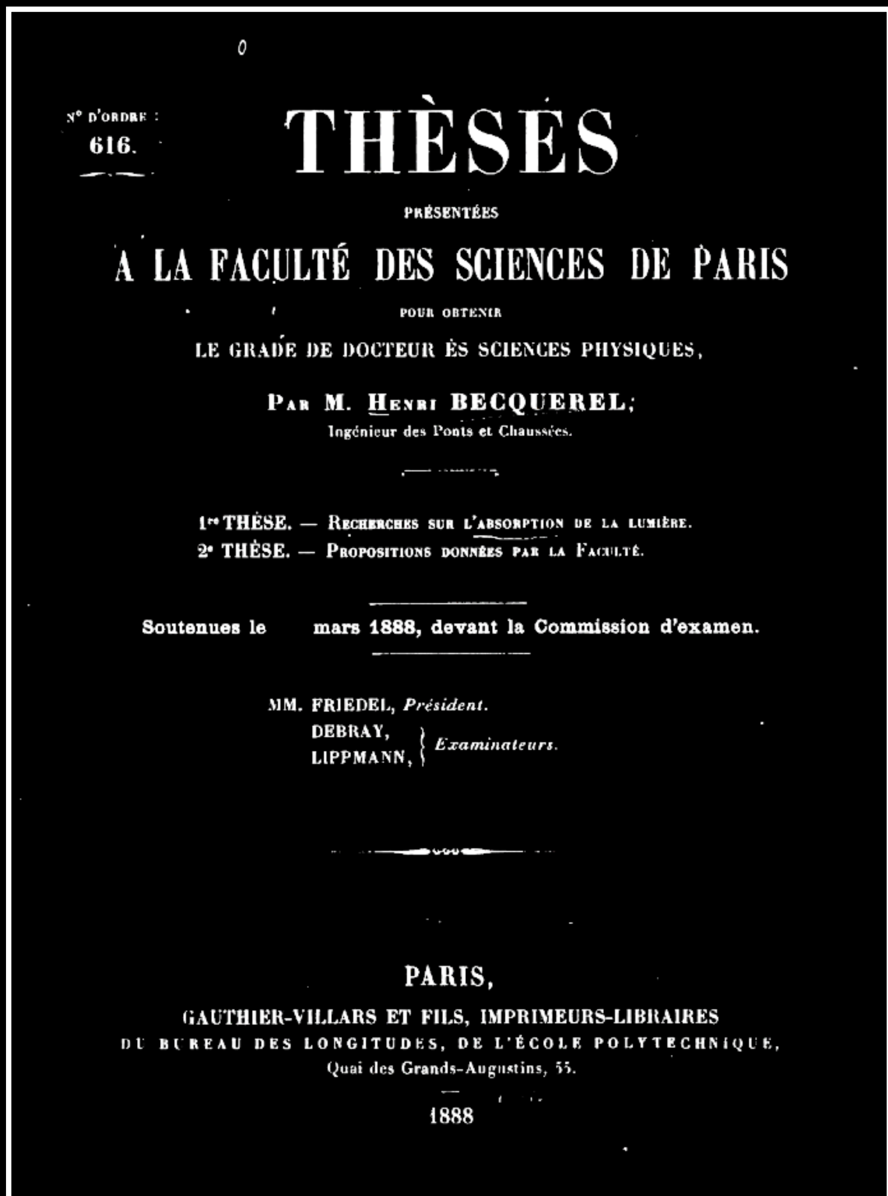


N° D'ORDRE : 616.

THÈSES

PRÉSENTÉES

A LA FACULTÉ DES SCIENCES DE PARIS

POUR OBTENIR

LE GRADE DE DOCTEUR ÈS SCIENCES PHYSIQUES,

PAR M. HENRI BECQUEREL,

Ingénieur des Ponts et Chaussées.

1re THÈSE. — RECHERCHES SUR L'ABSORPTION DE LA LUMIÈRE.

2e THÈSE. — PROPOSITIONS DONNÉES PAR LA FACULTÉ.

Soutenues le mars 1888, devant la Commission d'examen.

MM. FRIEDEL, *Président.*

DEBRAY, } *Examinateurs.*

LIPPMANN, }

PARIS,

GAUTHIER-VILLARS ET FILS, IMPRIMEURS-LIBRAIRES

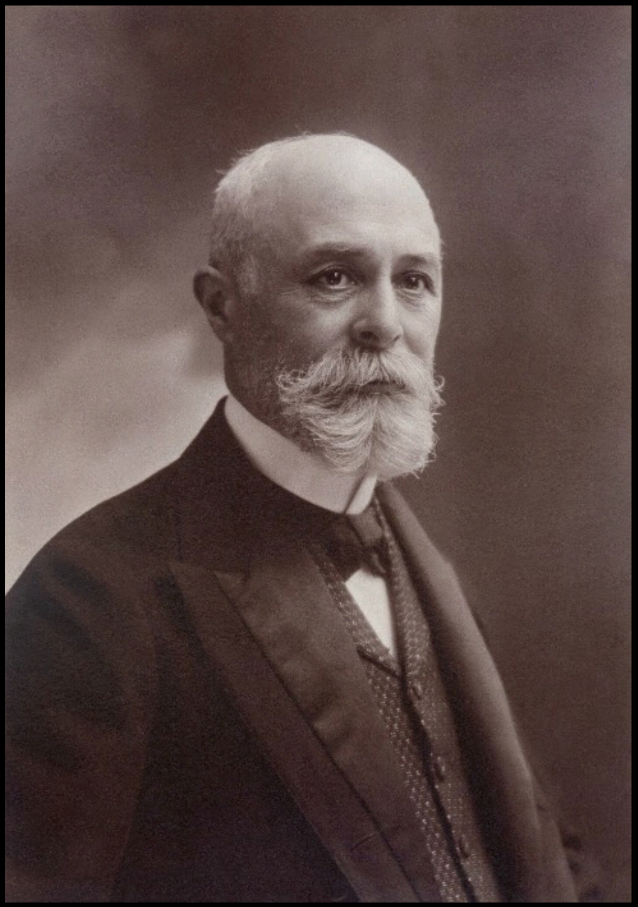
DU BUREAU DES LONGITUDES, DE L'ÉCOLE POLYTECHNIQUE,

Quai des Grands-Augustins, 55.

1888

His doctoral thesis:

“Researches on the absorption of light by crystals”



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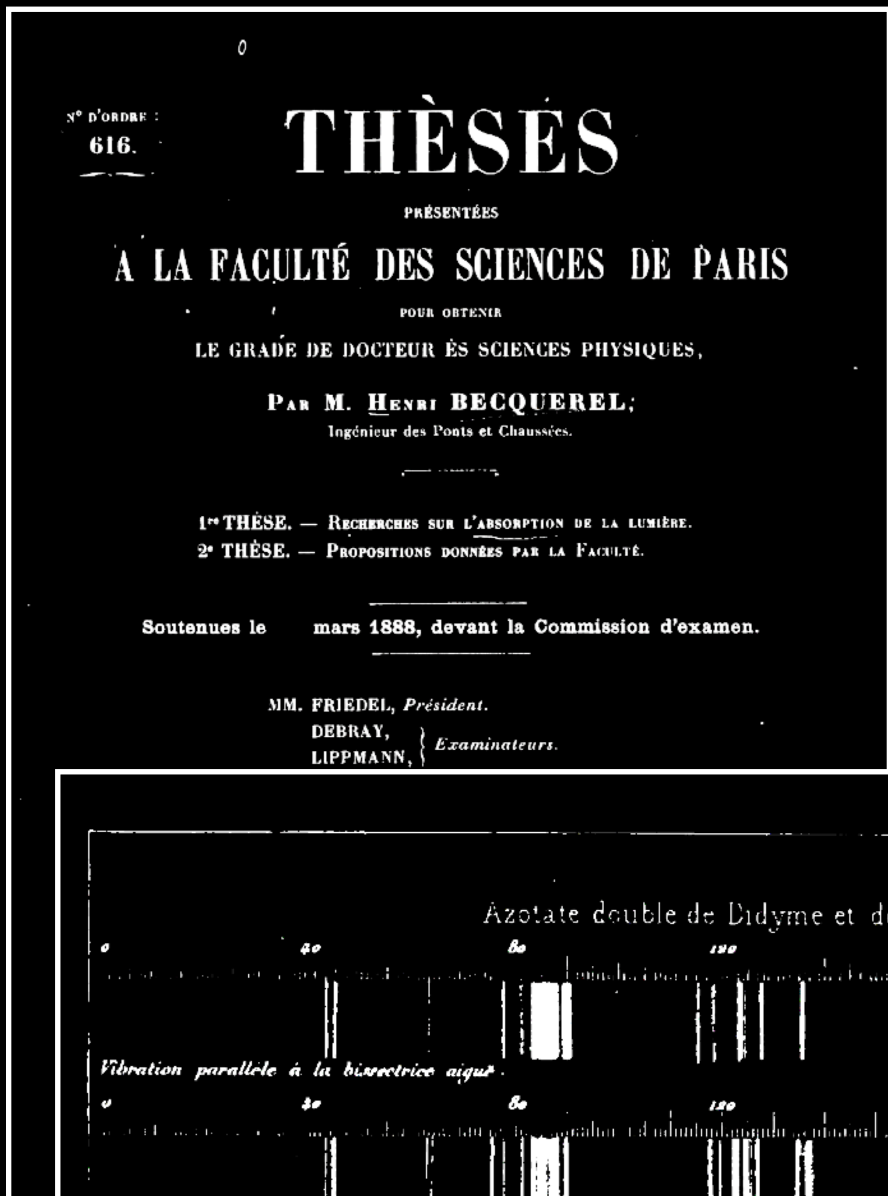

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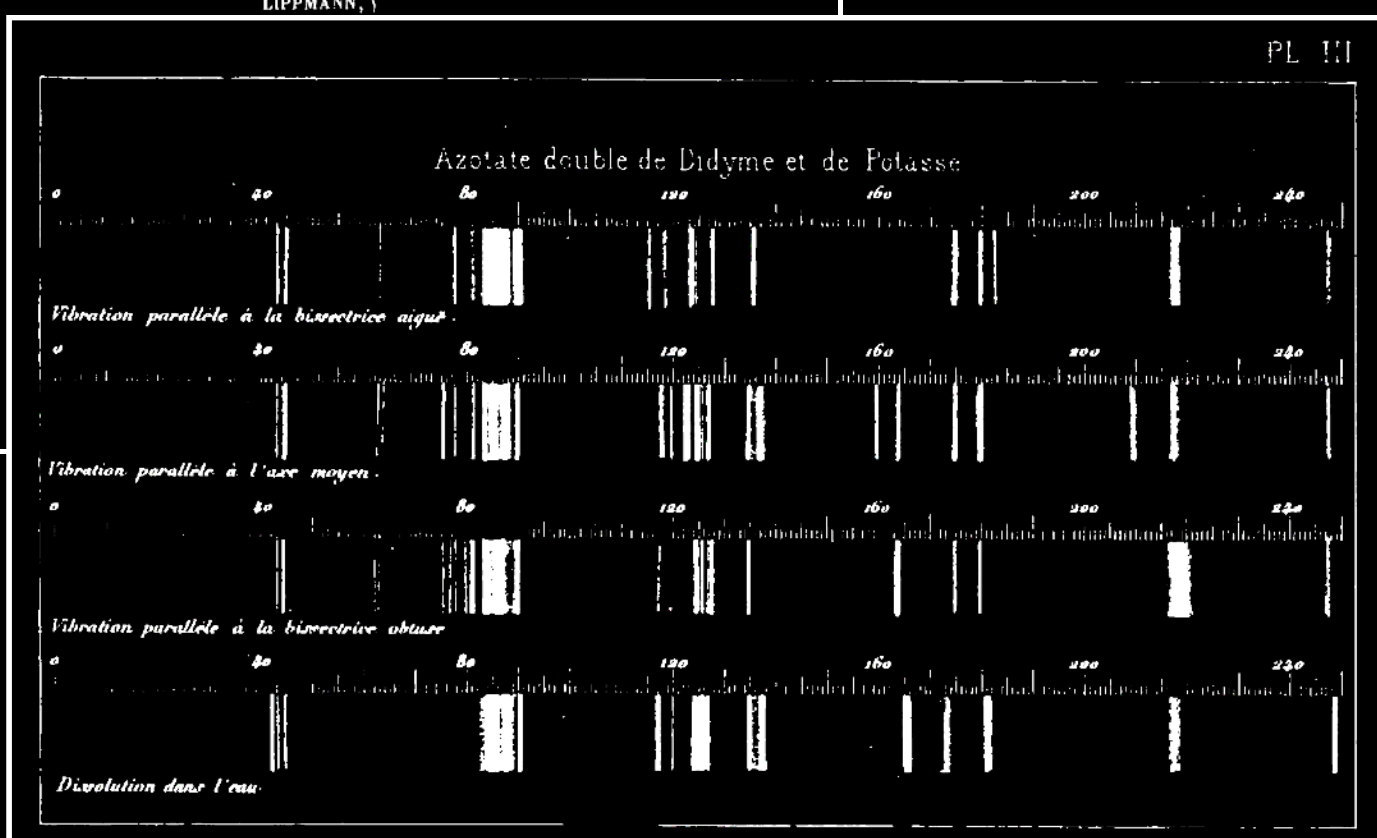

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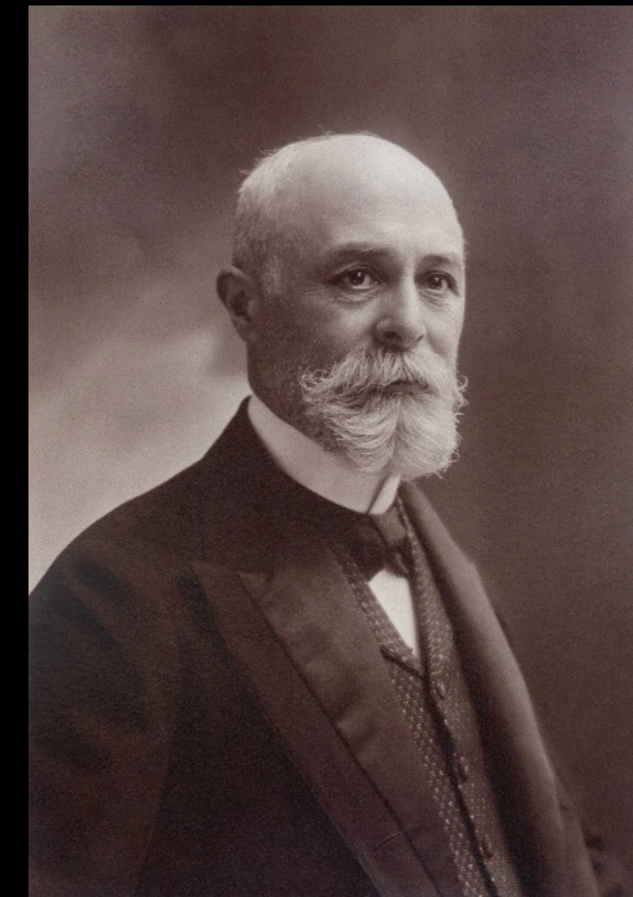

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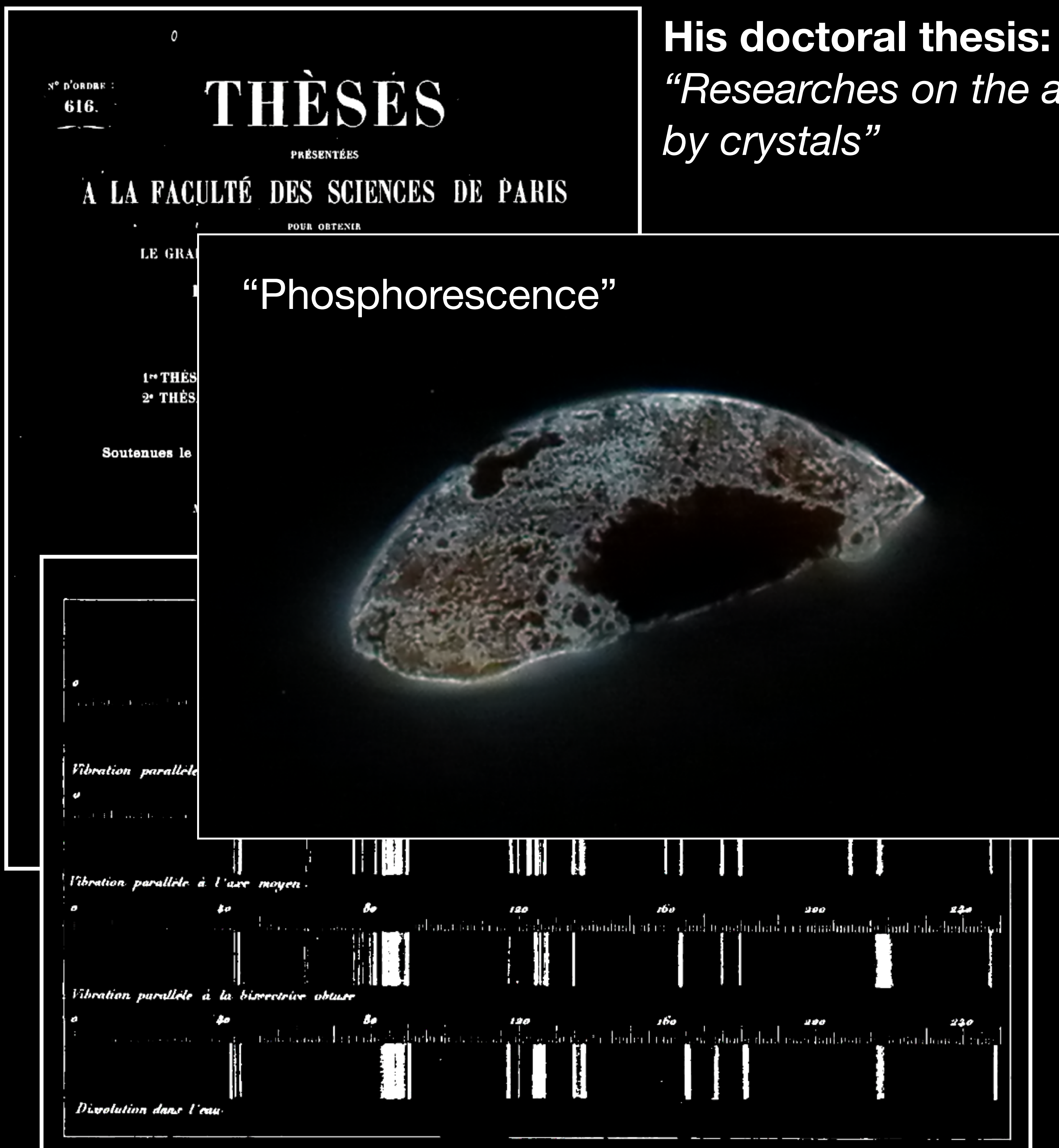

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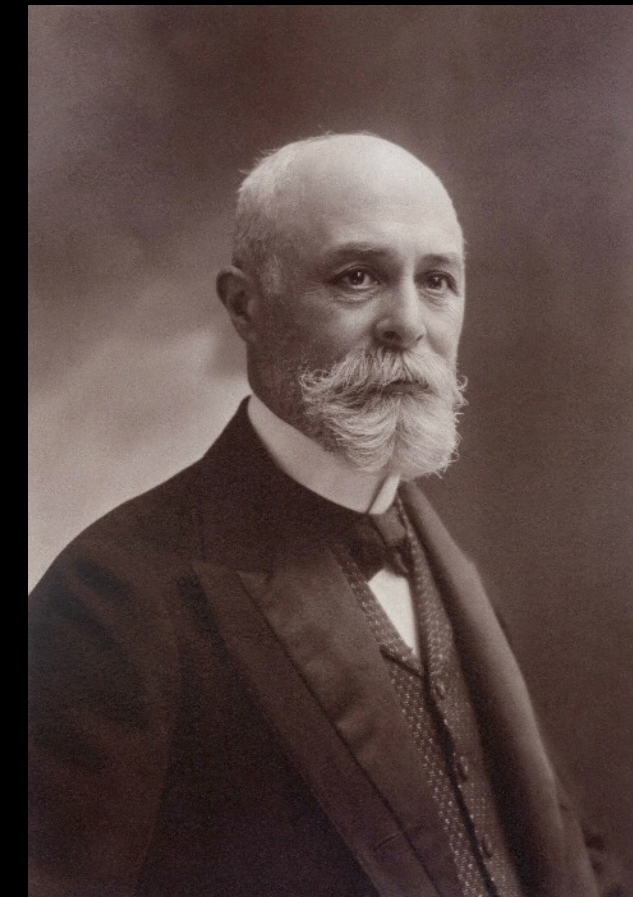

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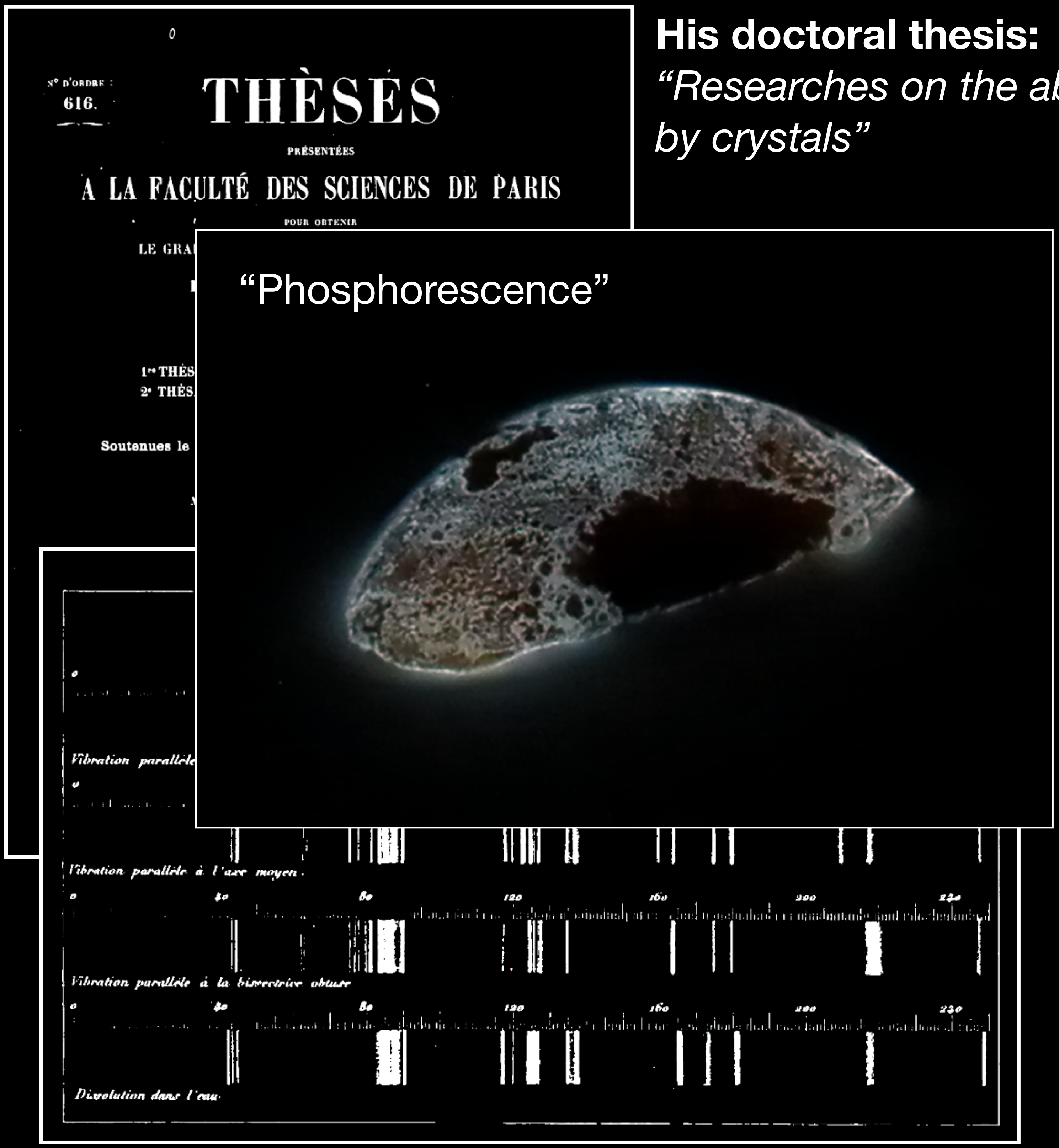

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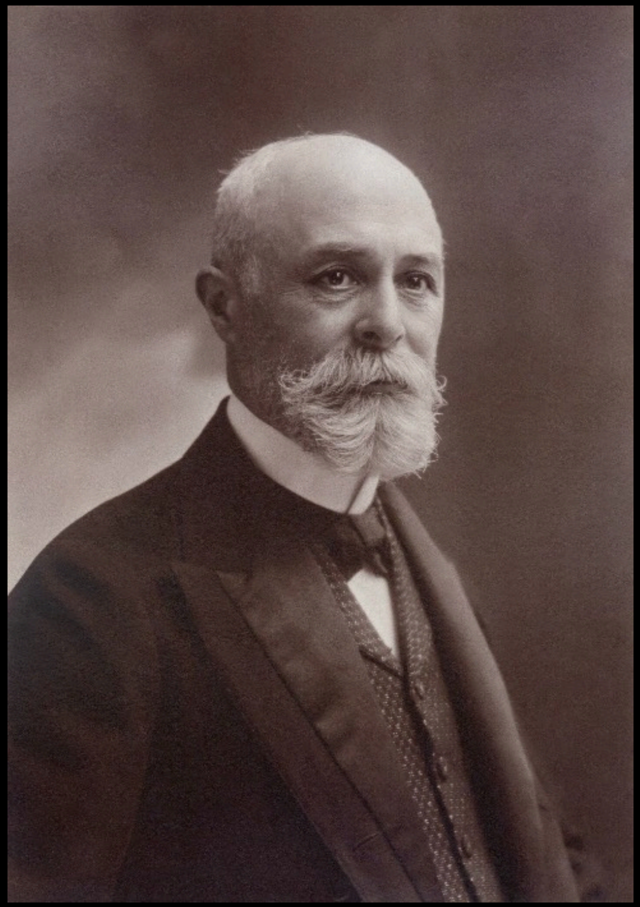
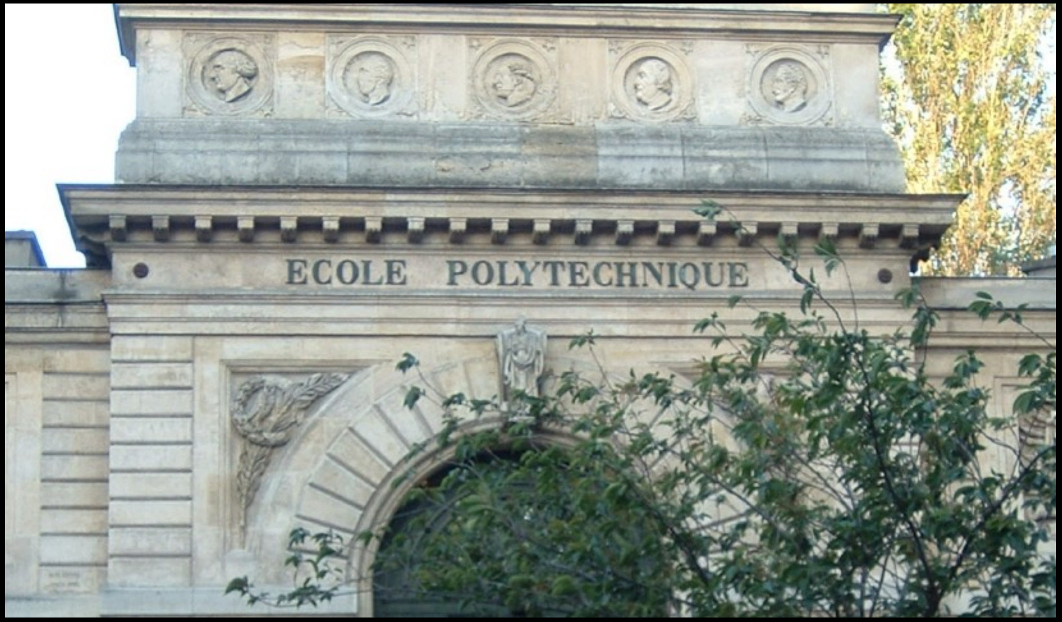
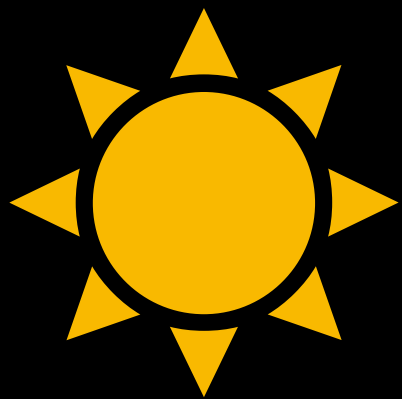


1895: Professor at Ecole Polytechnique
(Ca. 80 years after Sadi Carnot)



Phosphorescence and uranium



Uranium salt exposed
to sunlight …

“Phosphorescence”

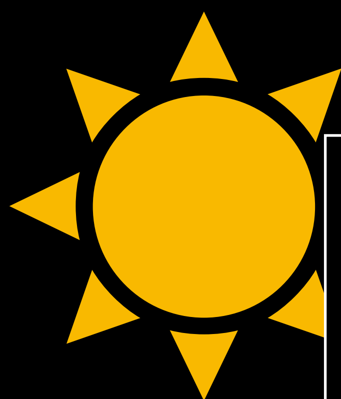
Phosphorescence and uranium

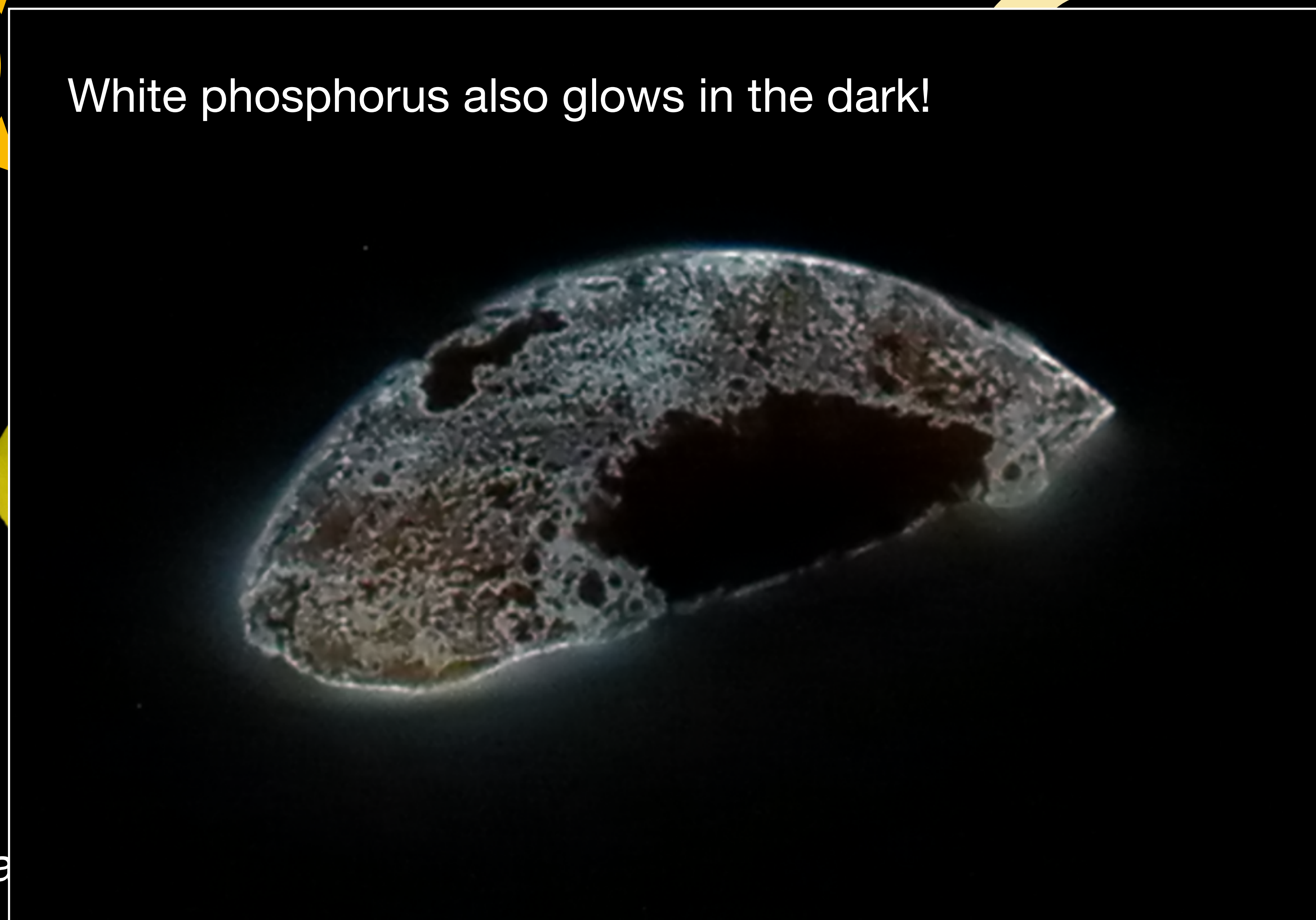
Uranium salt exposed
to sunlight …

… continues to glow
in the dark for a certain time

“Phosphorescence”

Phosphorescence and uranium





Ura

glow

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“Phosphorescence”

At the Academy of Sciences in 1896

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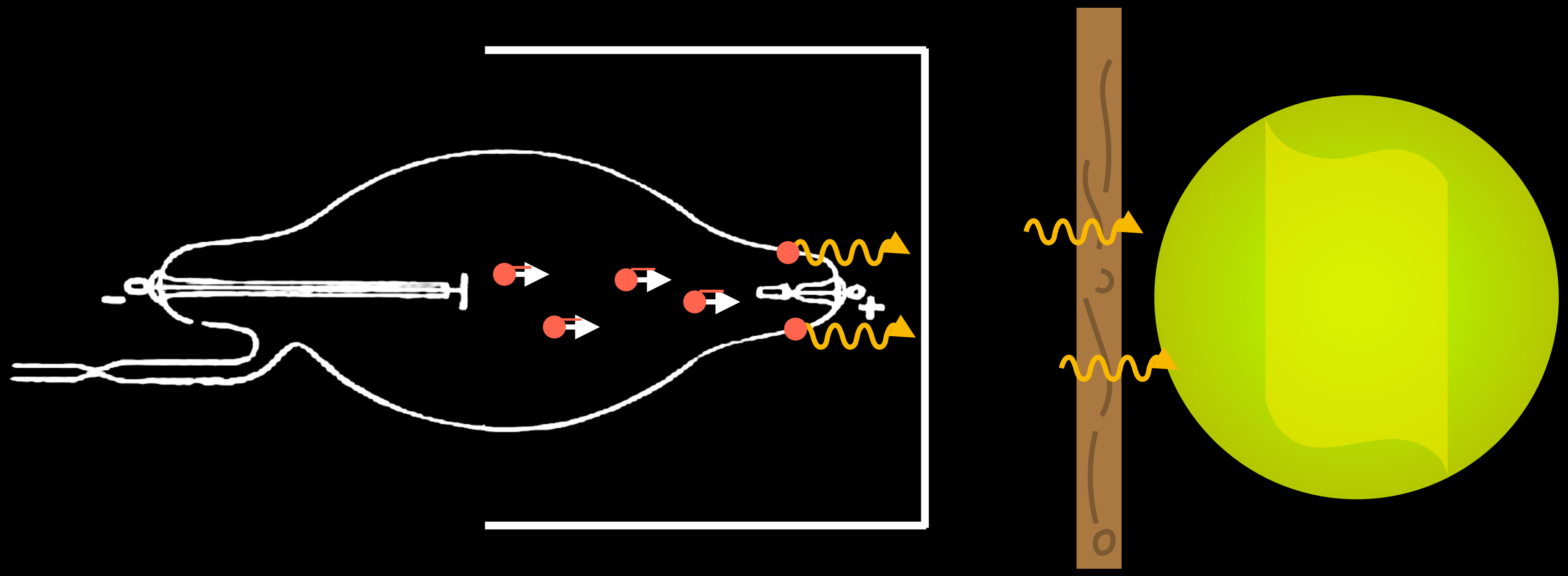

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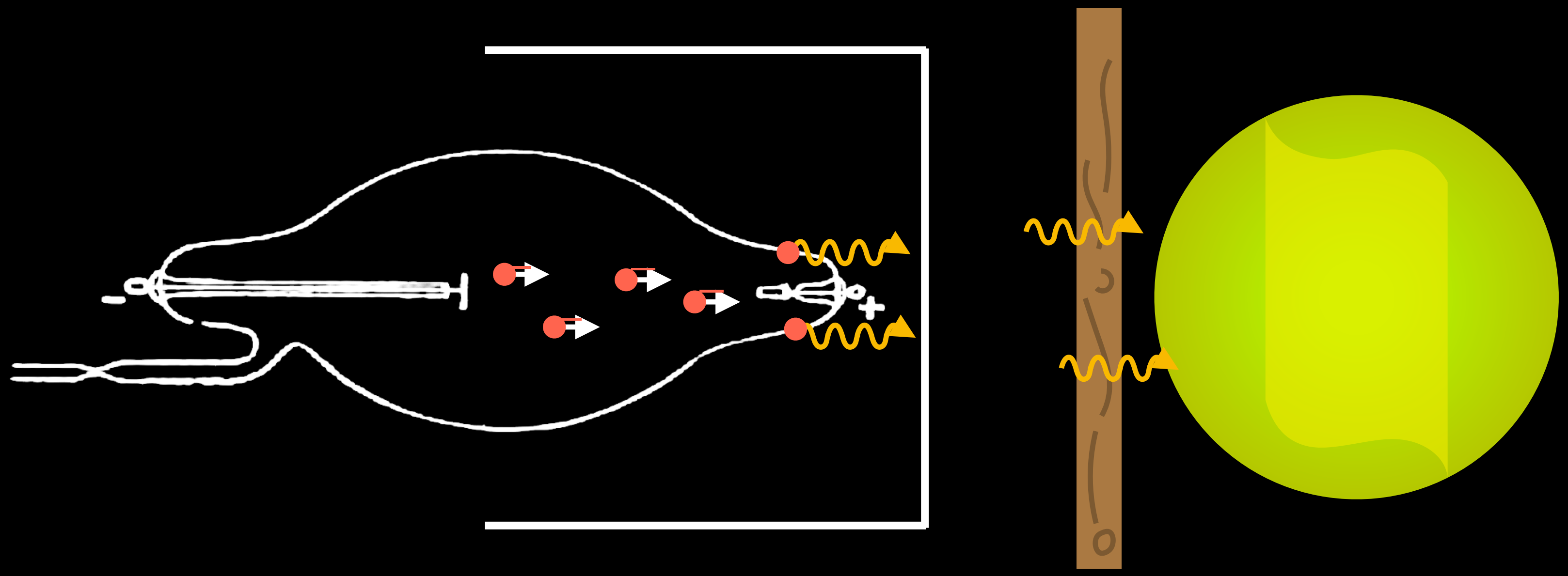
“I was answered that the origin of the radiation was the luminous spot of the wall of the tube that received the cathodic flux.”



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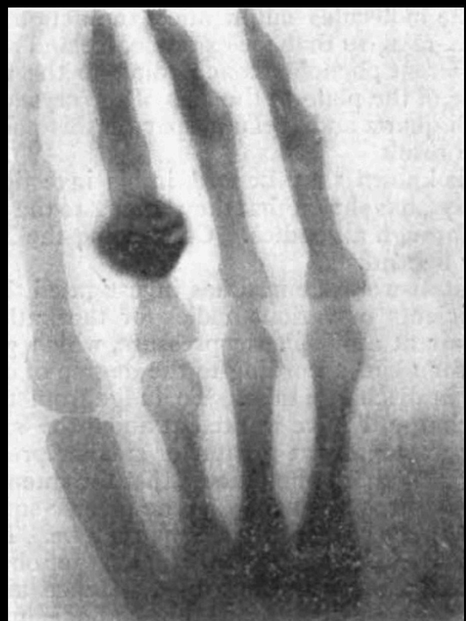

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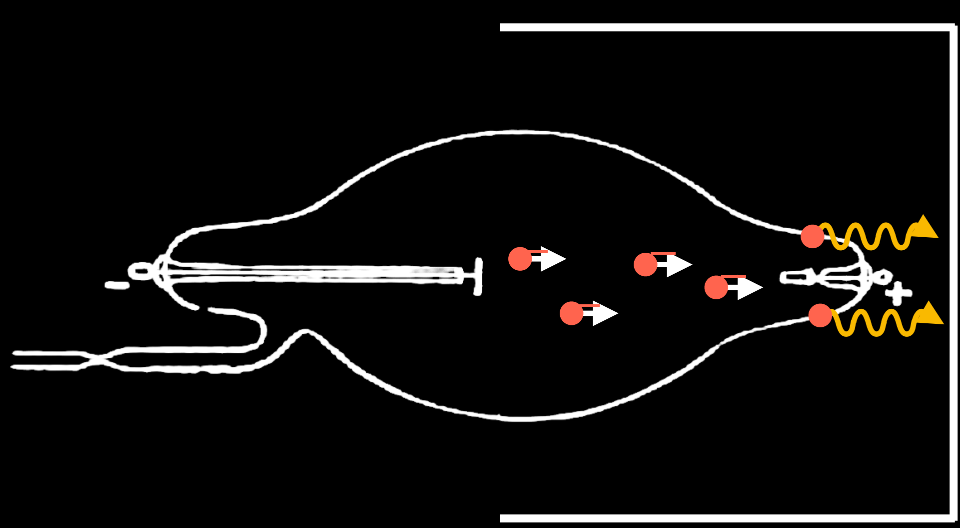

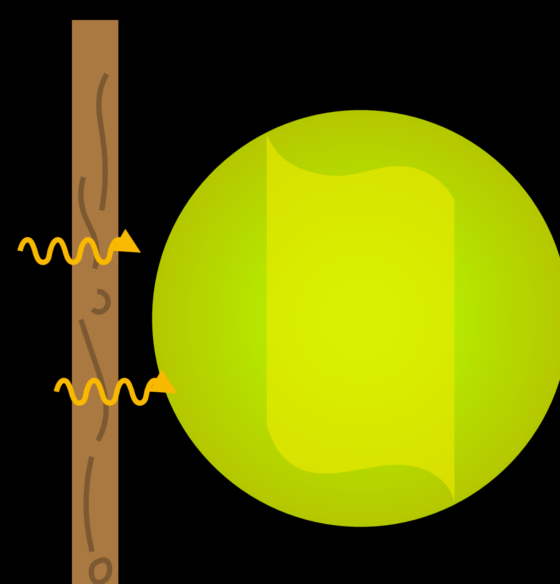

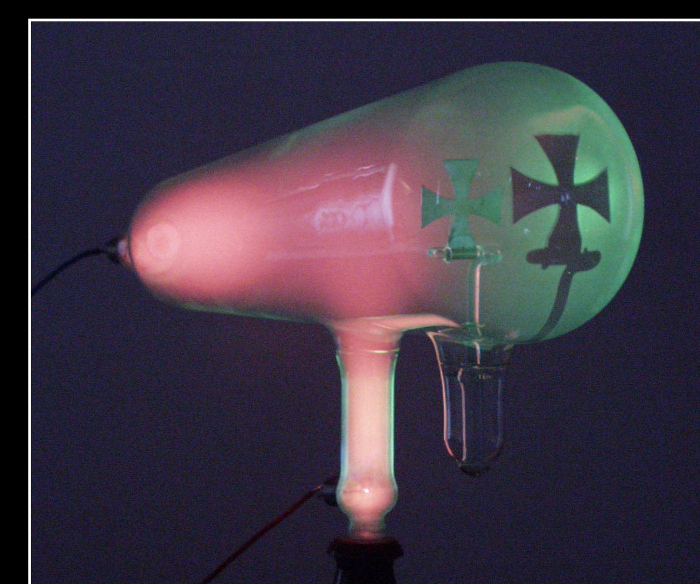

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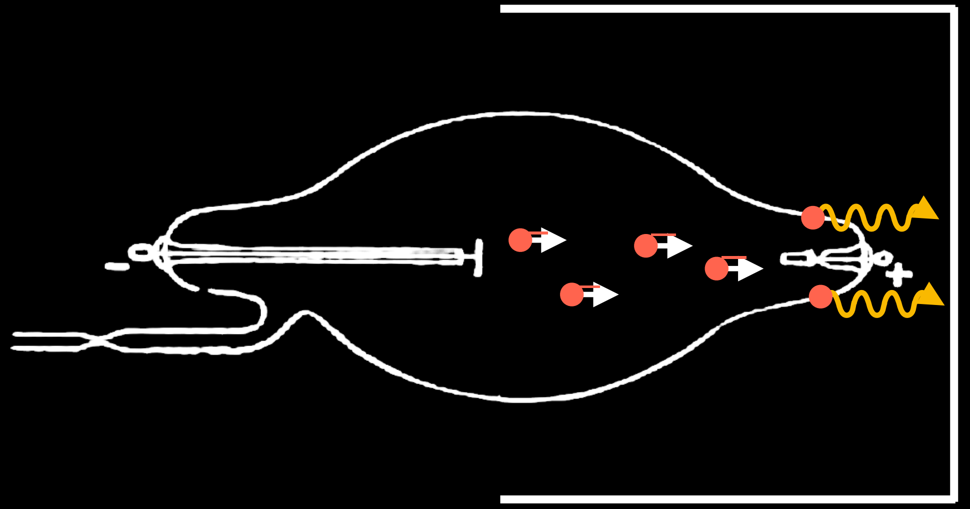
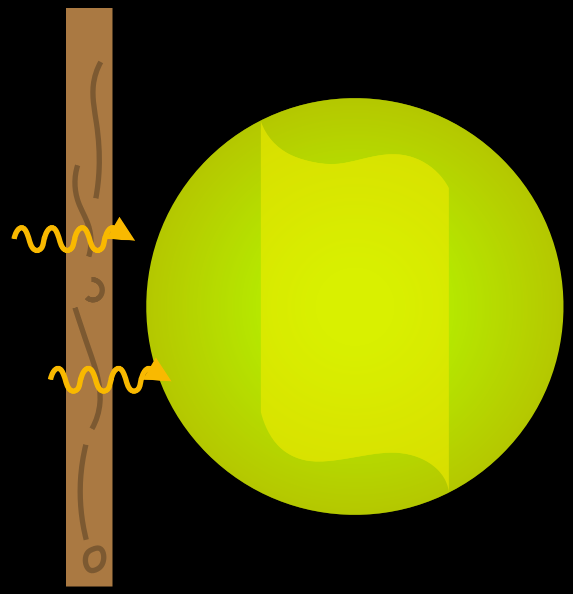
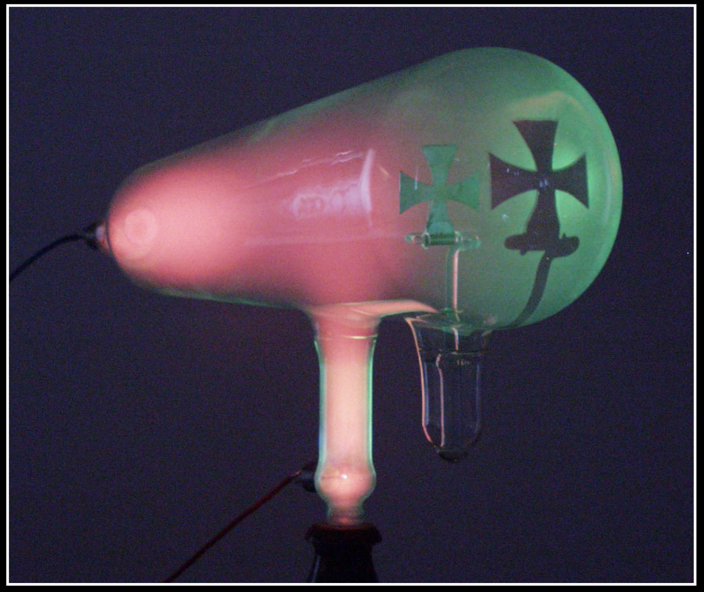
"I asked my colleague what was the place of emission of those rays, in the vacuum tube that produced X-rays."

"I was answered that the origin of the radiation was the luminous spot of the wall of the tube that received the cathodic flux."

"I cogitated at once to search whether the new emission was a manifestation of the phenomenon that gave birth to the phosphorescence and whether all phosphorescent bodies emit similar rays."







A chance discovery

“A Lumière plate was enclosed in an opaque case of black cloth.”

[source]

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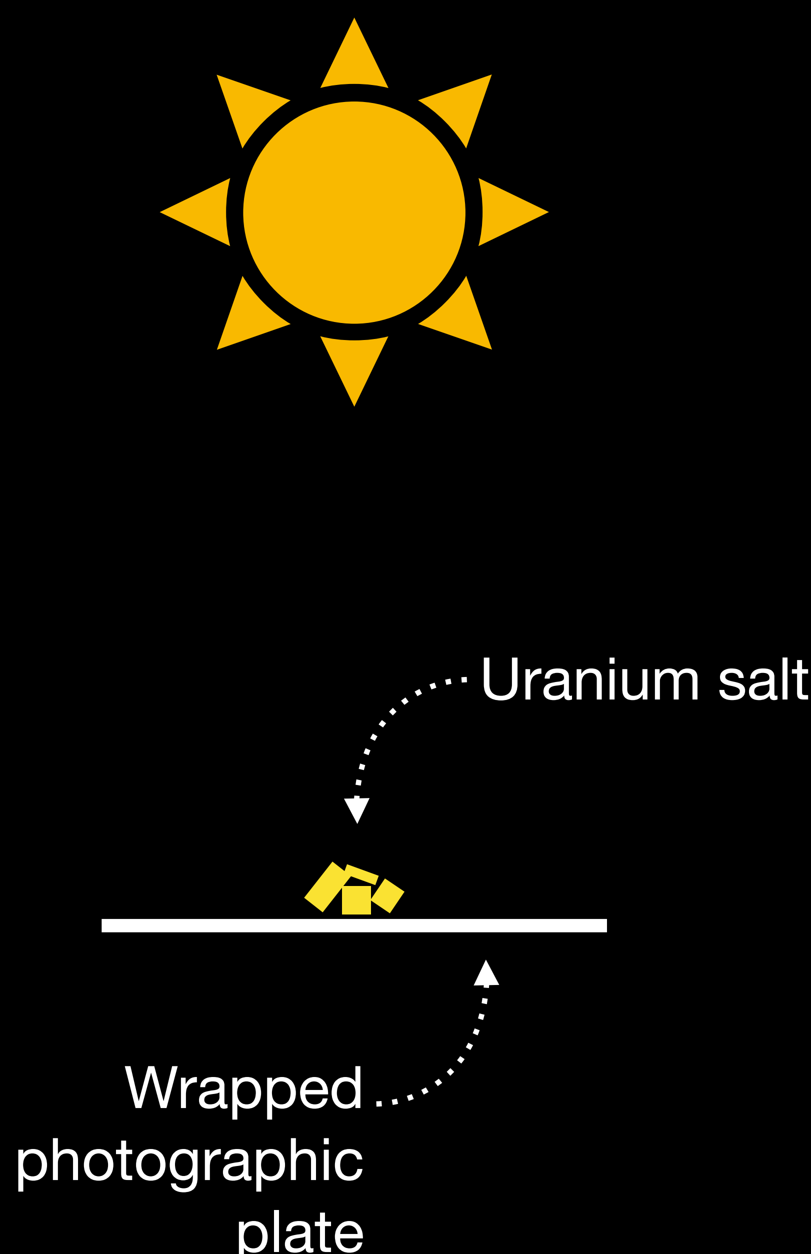

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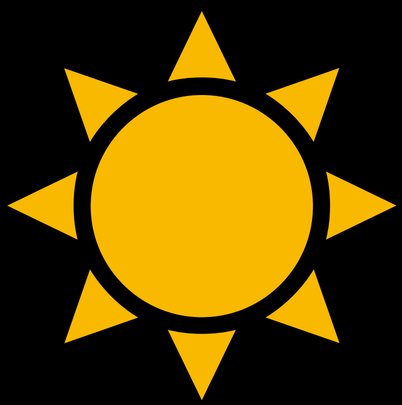

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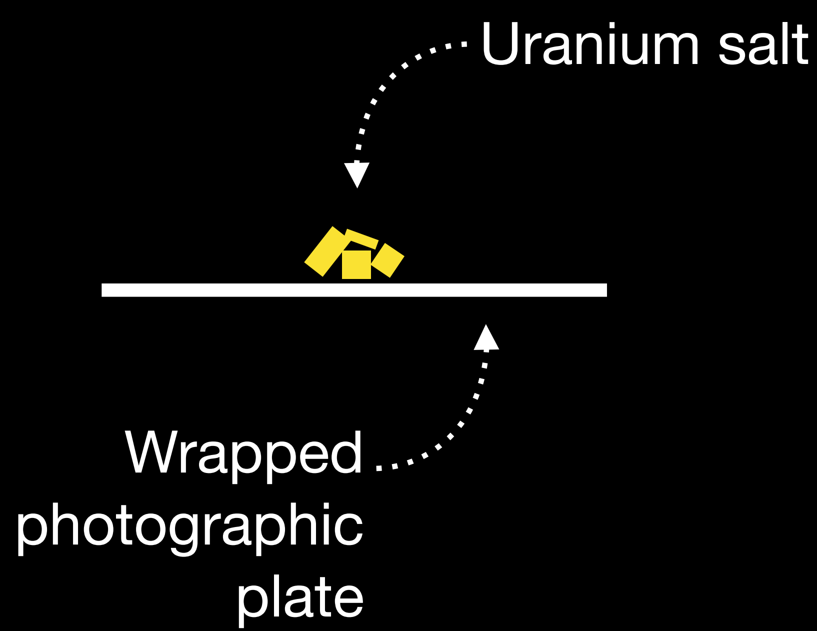

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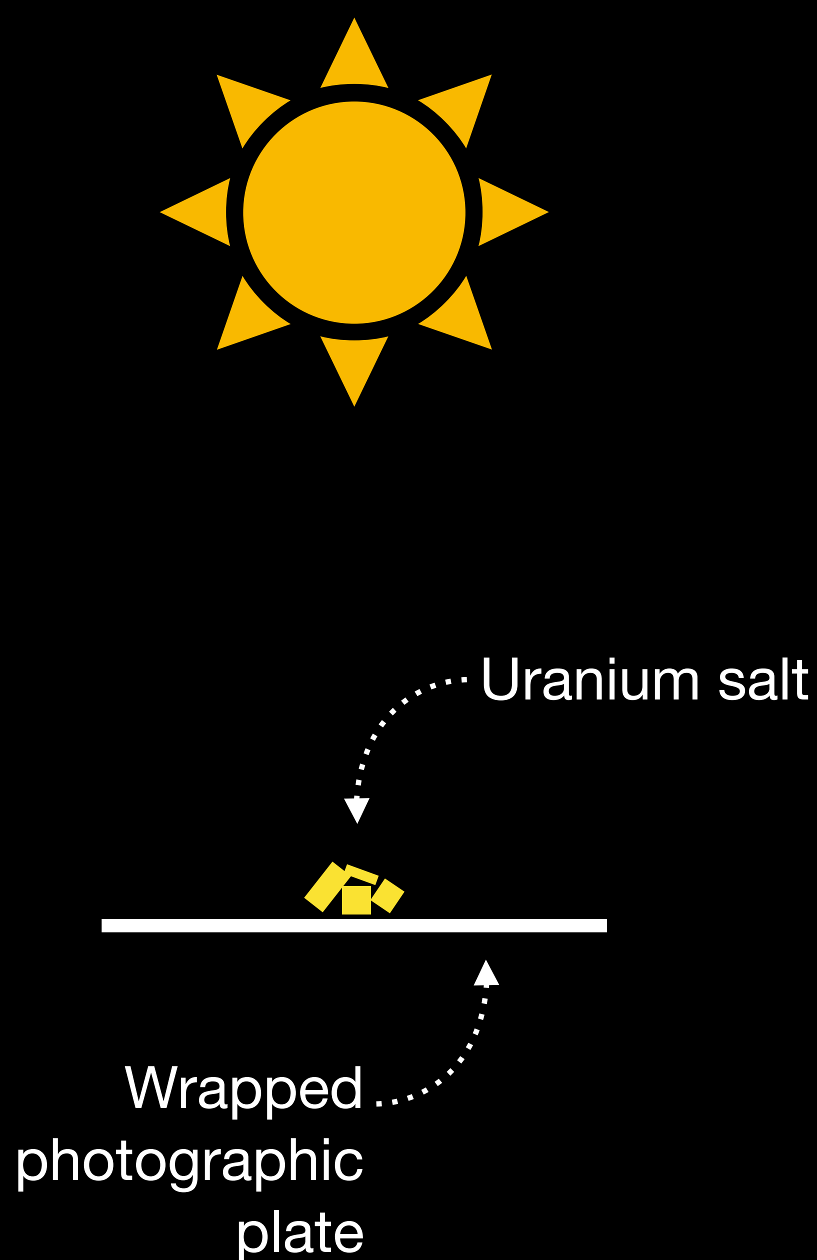

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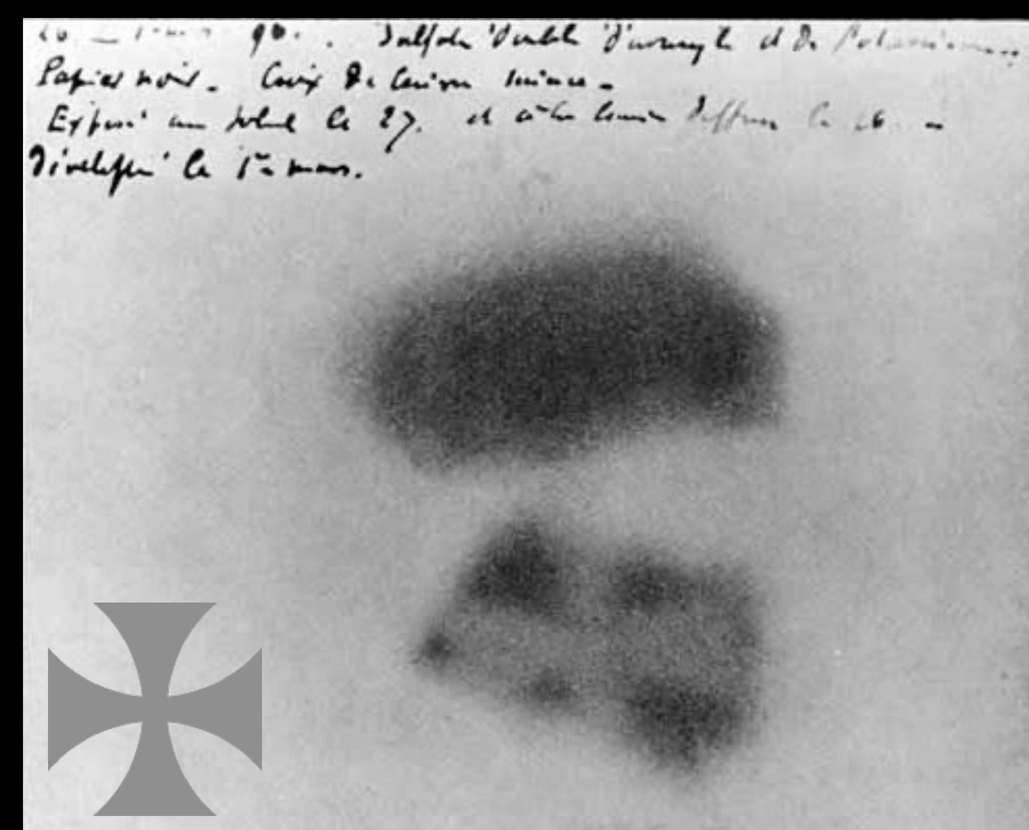

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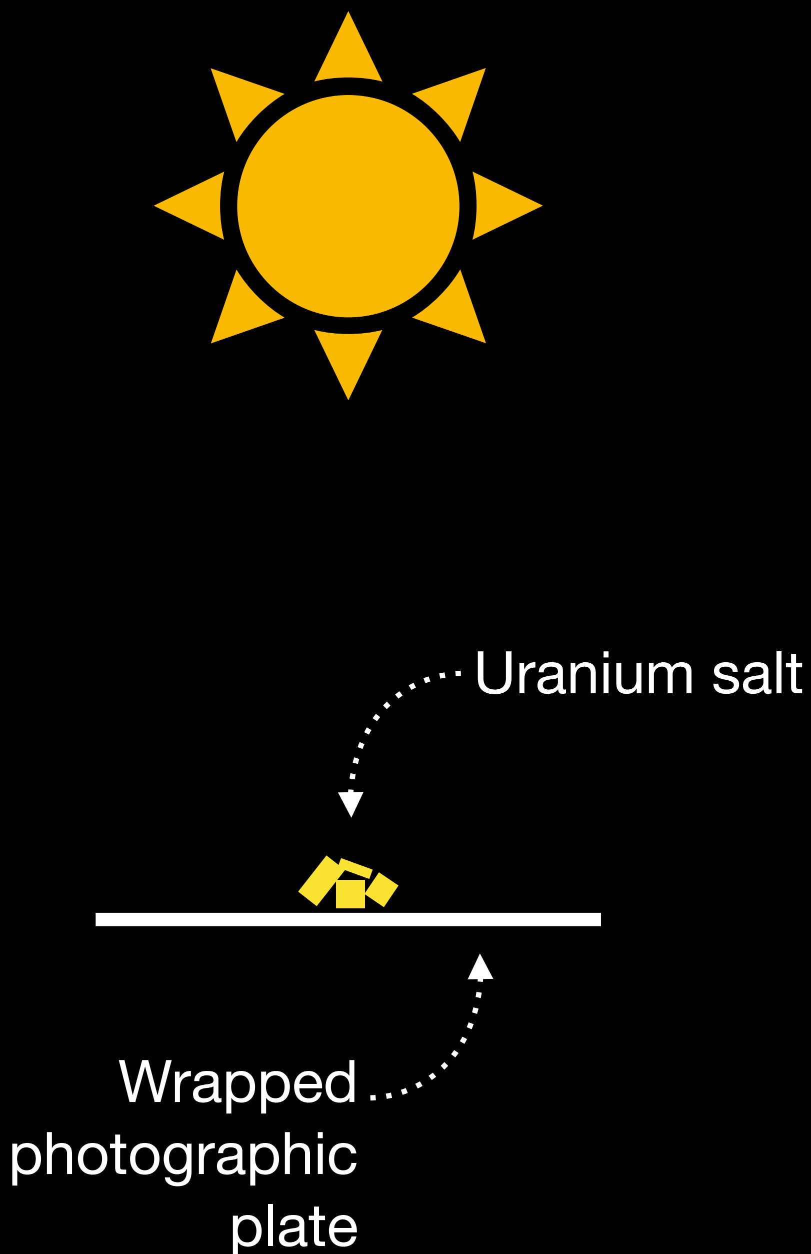

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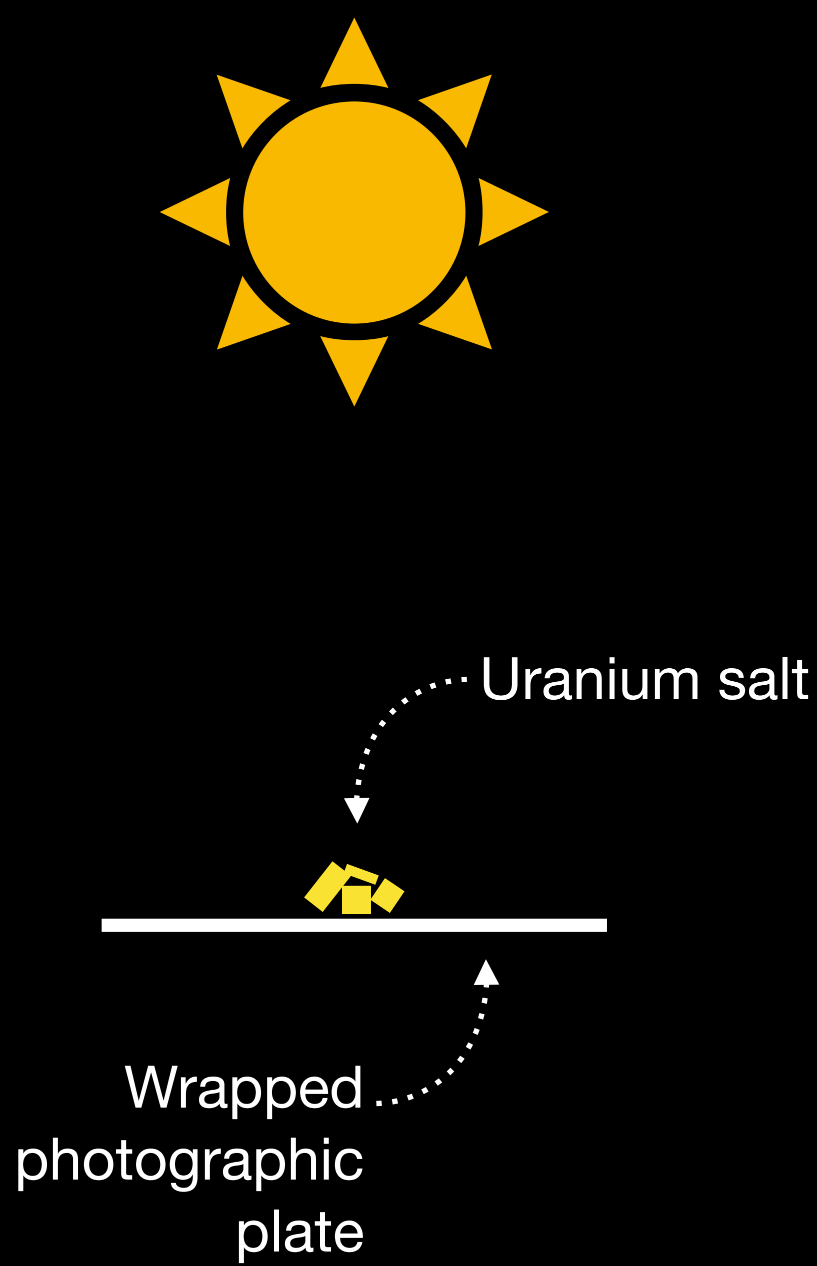

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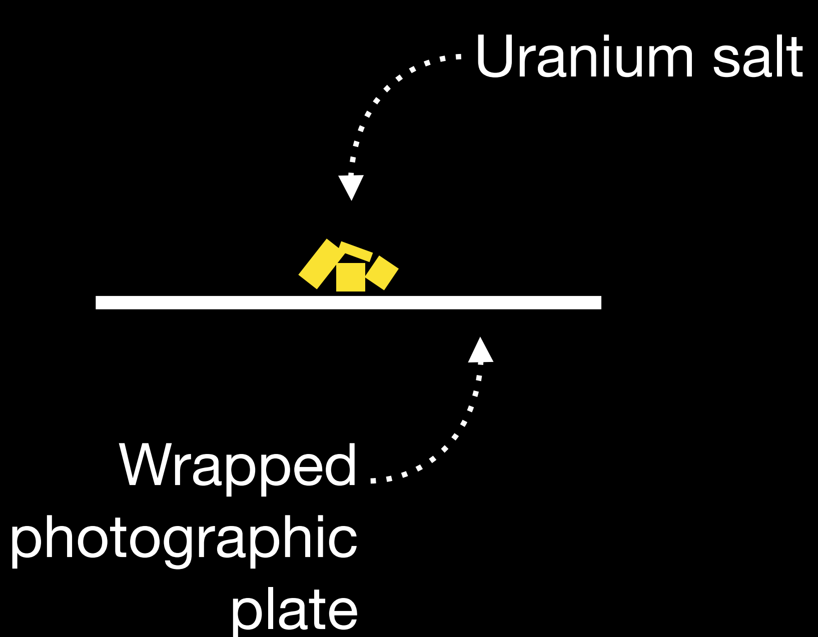

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"The same crystalline crusts, arranged the same way, in the same conditions and through the same screens, but kept in darkness, still produce the same photographic images."

A chance discovery

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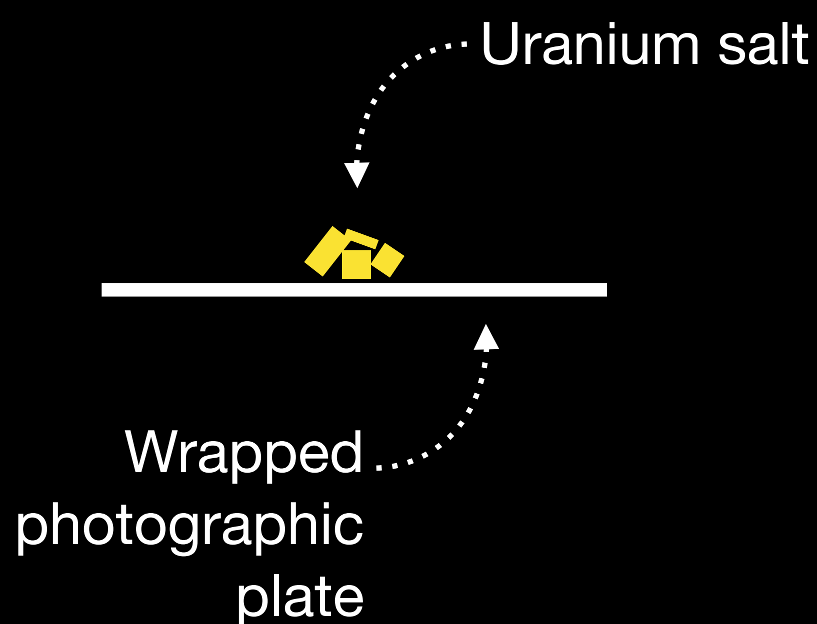

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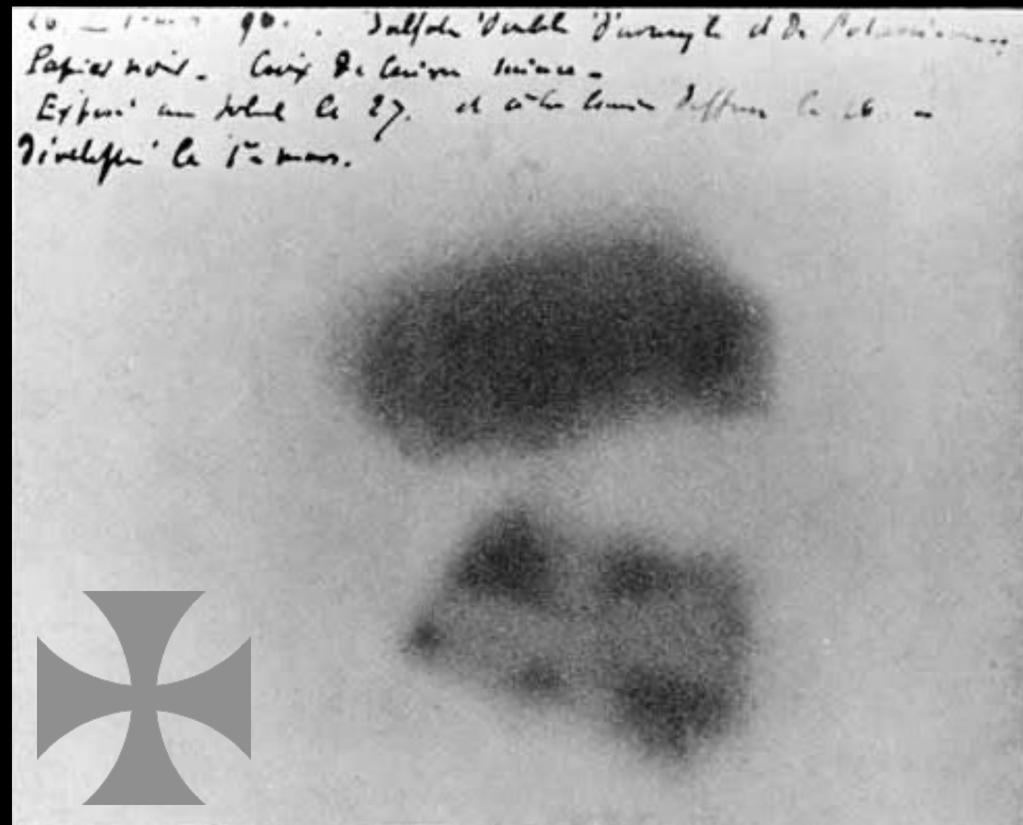

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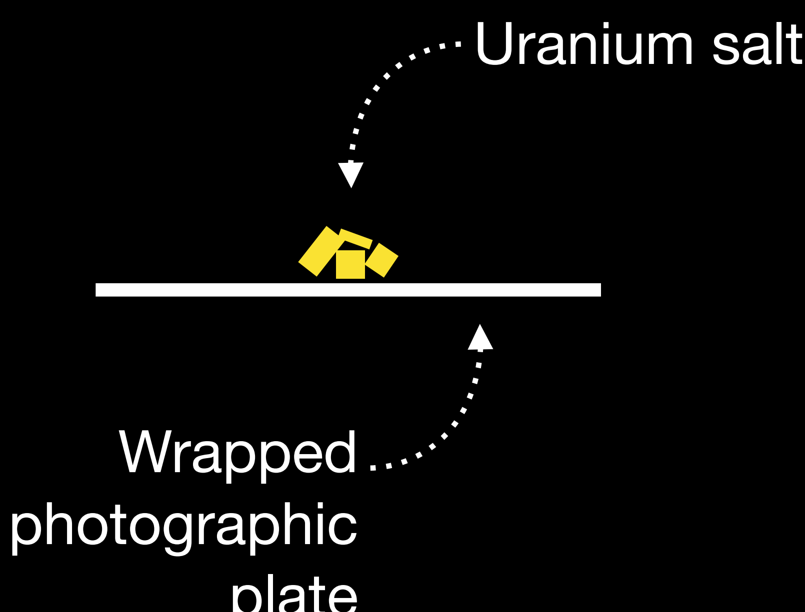

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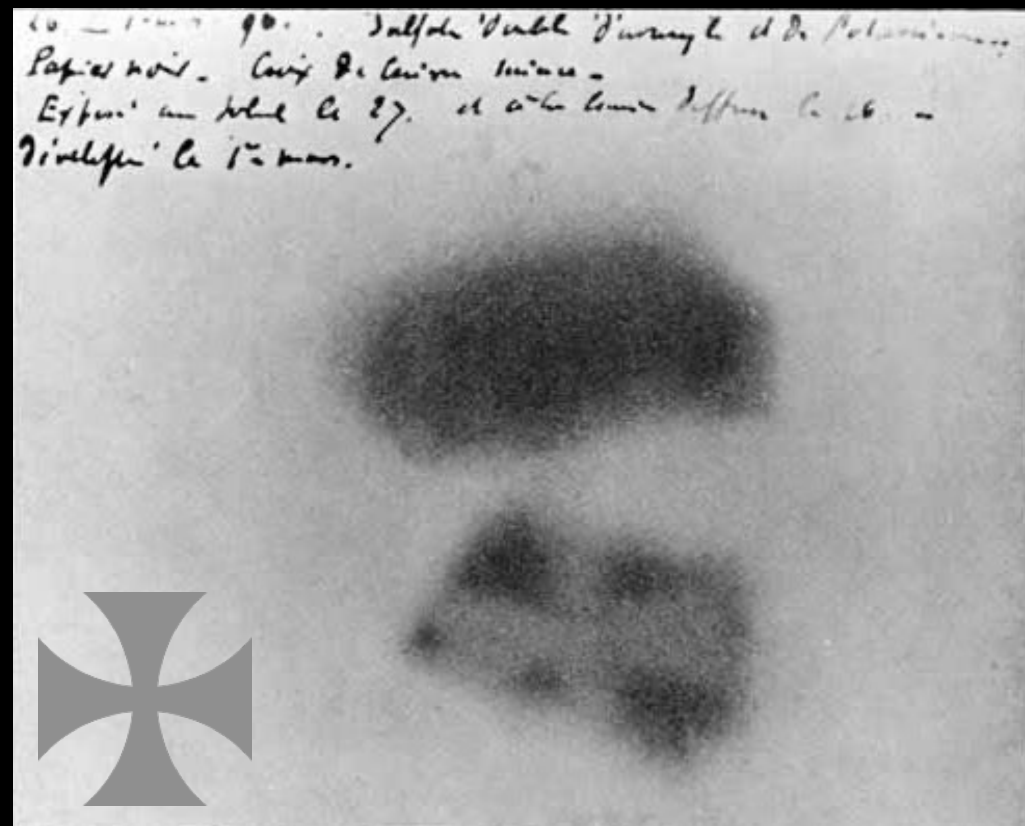

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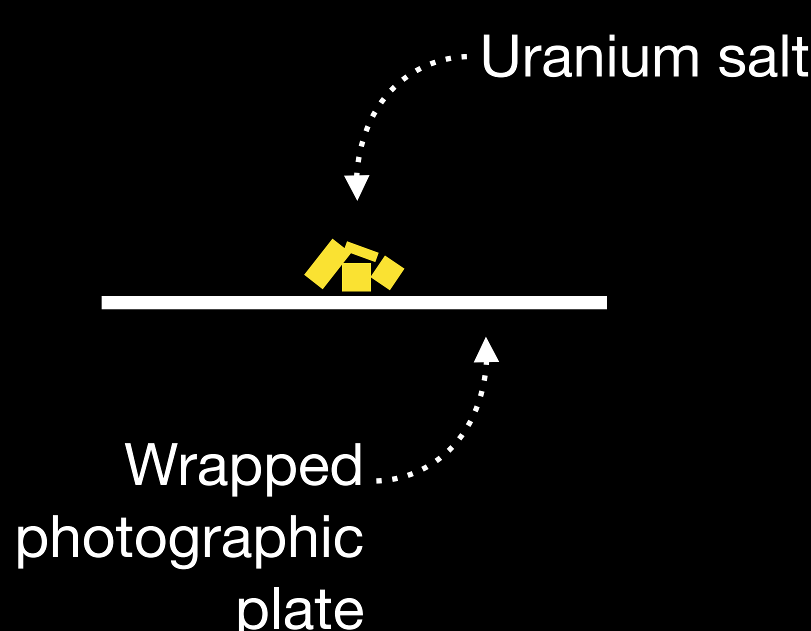
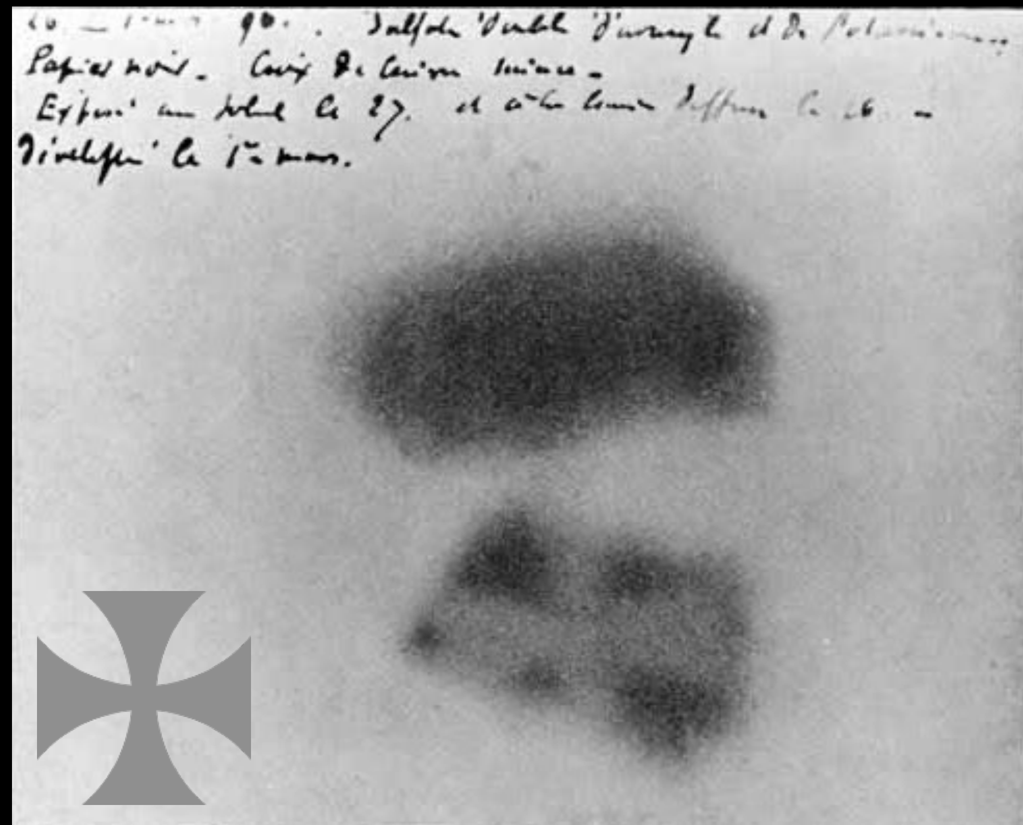


“The same crystalline crusts, arranged the same way, in the same conditions and through the same screens, but kept in darkness, still produce the same photographic images.”

It’s not about the sun nor phosphorescence at all!

A chance discovery

“A Lumière plate of black cloth.”



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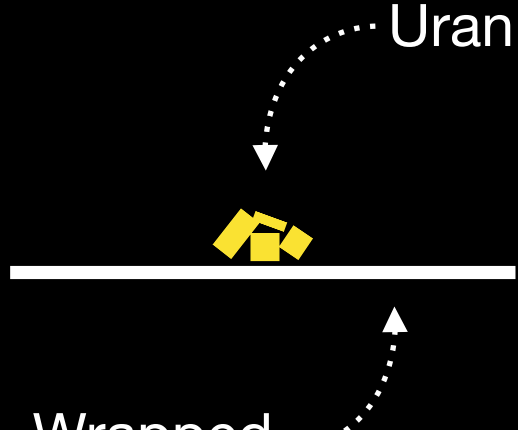
Uraniu



Wrapped photographic plate

“These effects have a great similarity to the effects produced by the rays studied by Mr. Röntgen.”

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It’s not about the sun nor phosphorescence at all!

Marie Skłodowska-Curie

Marie Skłodowska-Curie

From Poland to Paris:
A pact between sisters

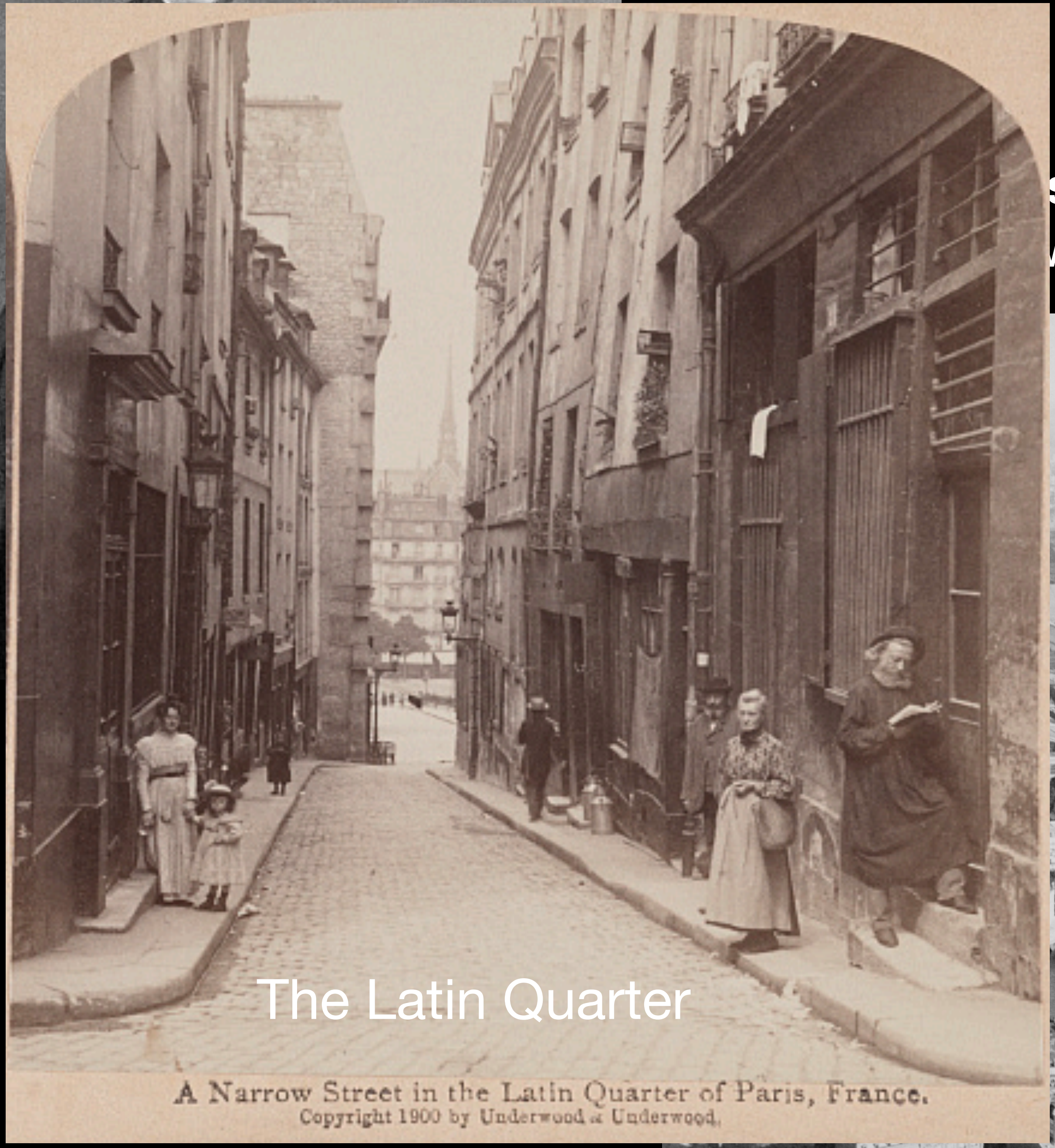
Marie Skłodowska-Curie

From Poland to Paris:
A pact between sisters

Arrived in Paris in 1891:
Just after the World's Fair in 1889

Marie Skłodowska-Curie

From Poland to Paris:
A pact between sisters



s in 1891:
/orld's Fair in 1889

Marie Skłodowska-Curie

From Poland to Pa
A pact between sist

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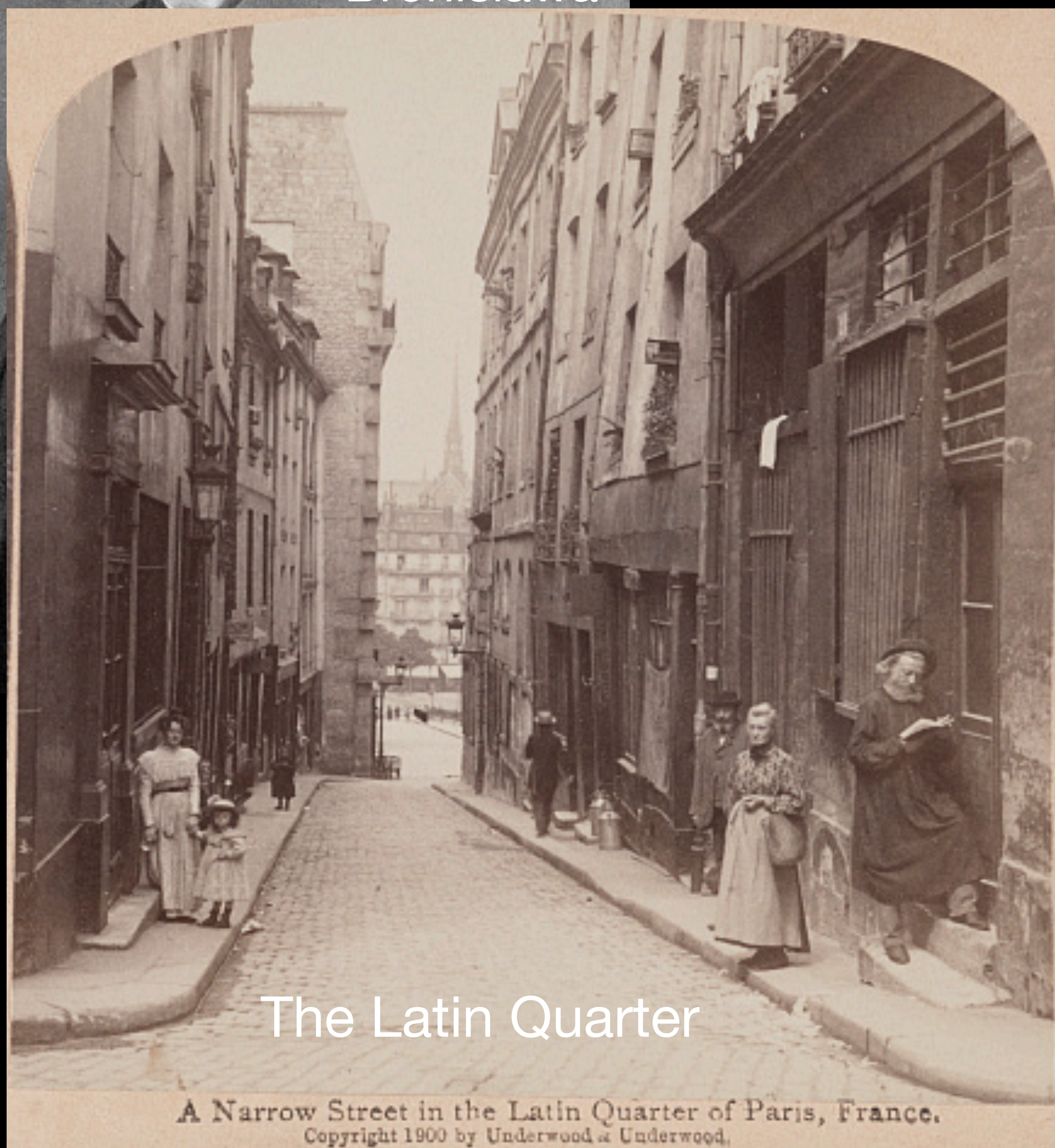
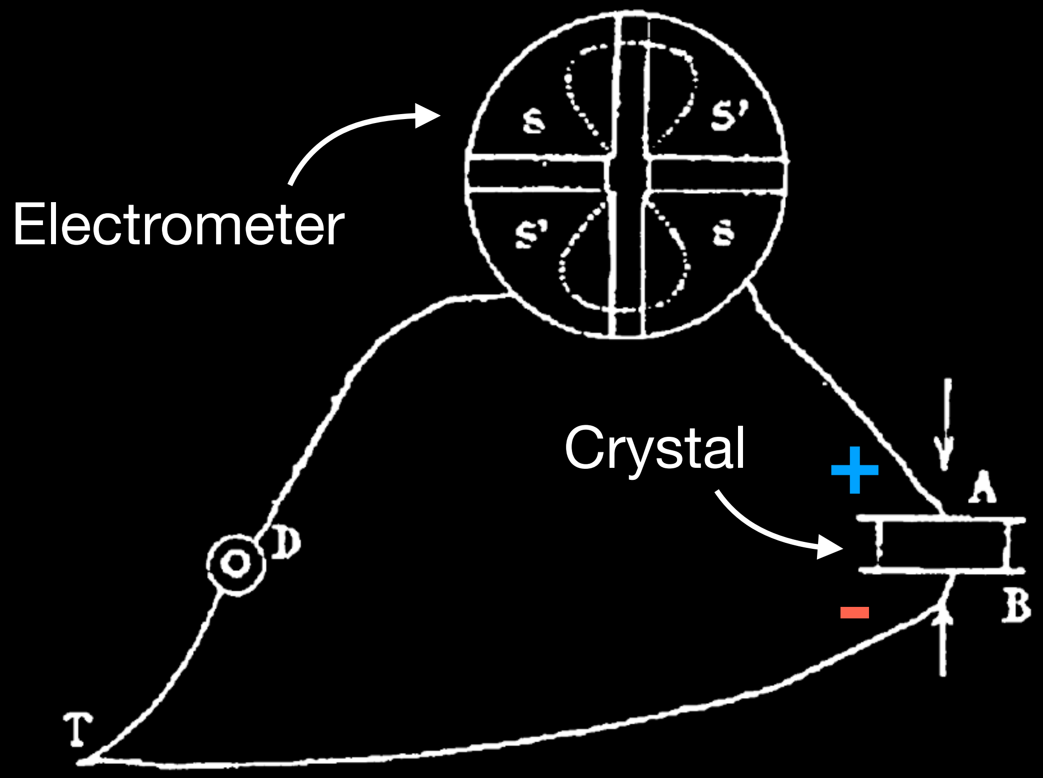


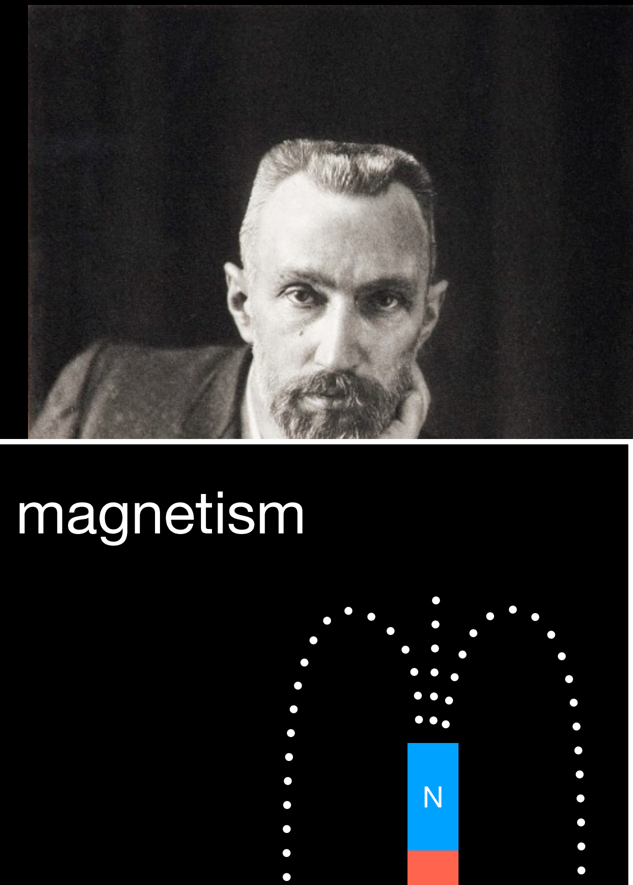
Pierre Curie

Pierre Curie

1880: the Curie brothers discover the piezoelectric effect



Pierre Curie



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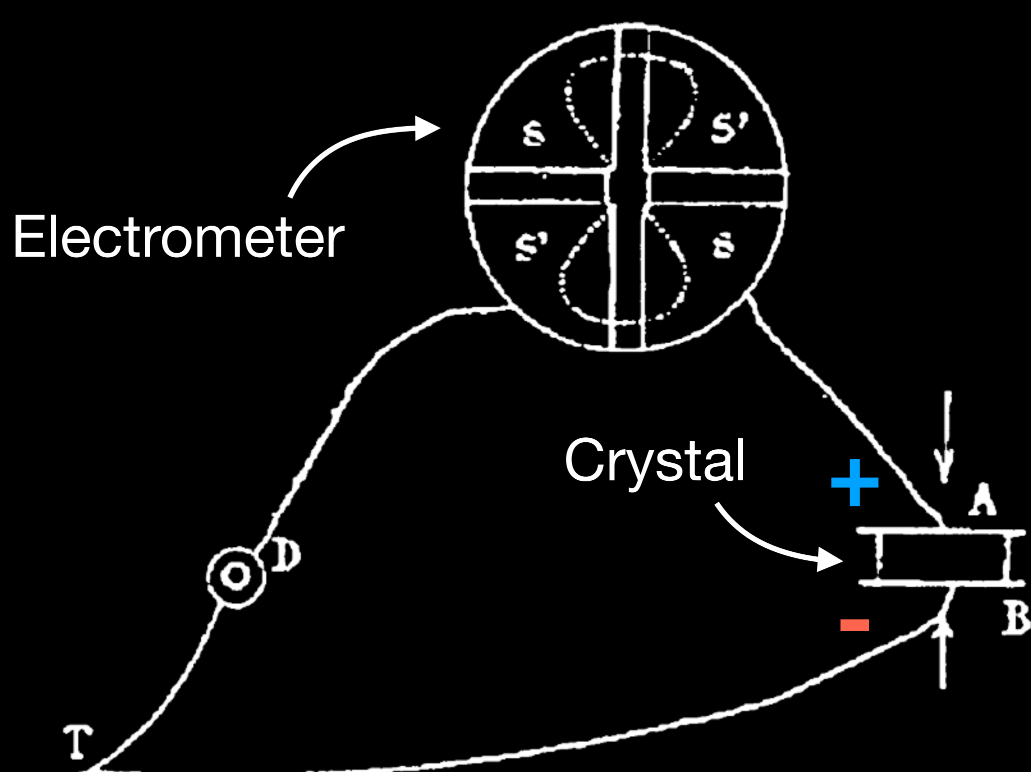
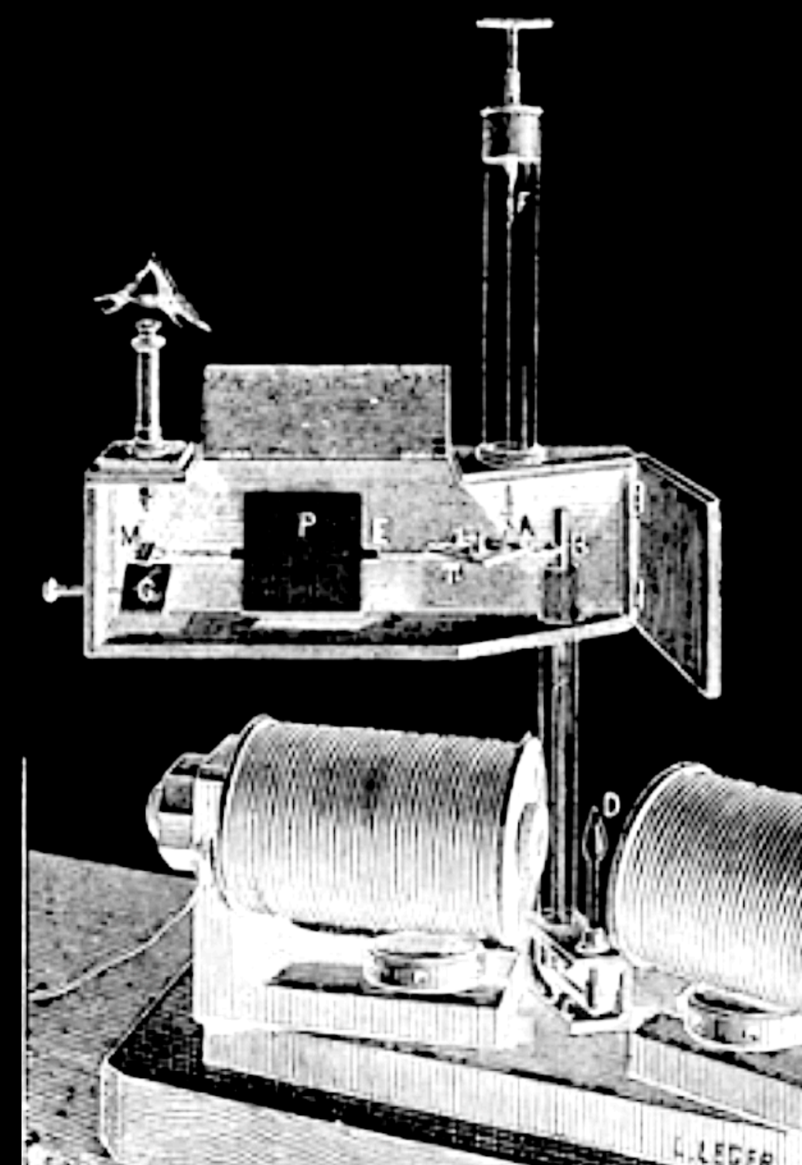
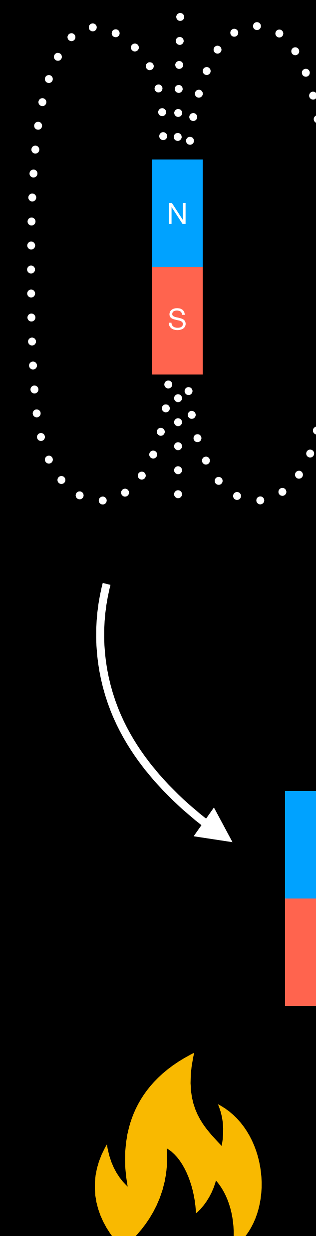


1895: Magnets lose their magnetism when heated up!

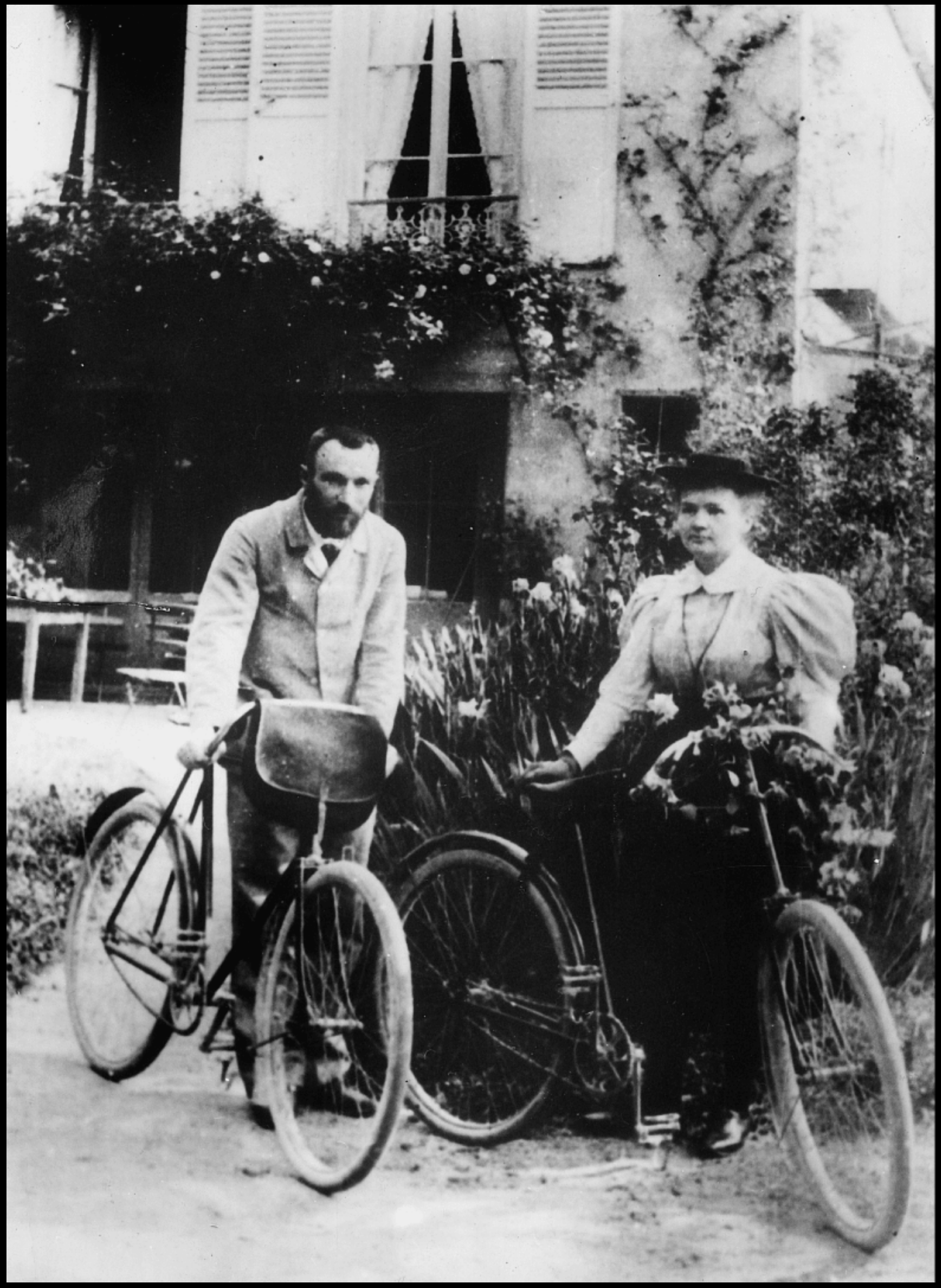




The Curies in 1895

The Curies in 1895

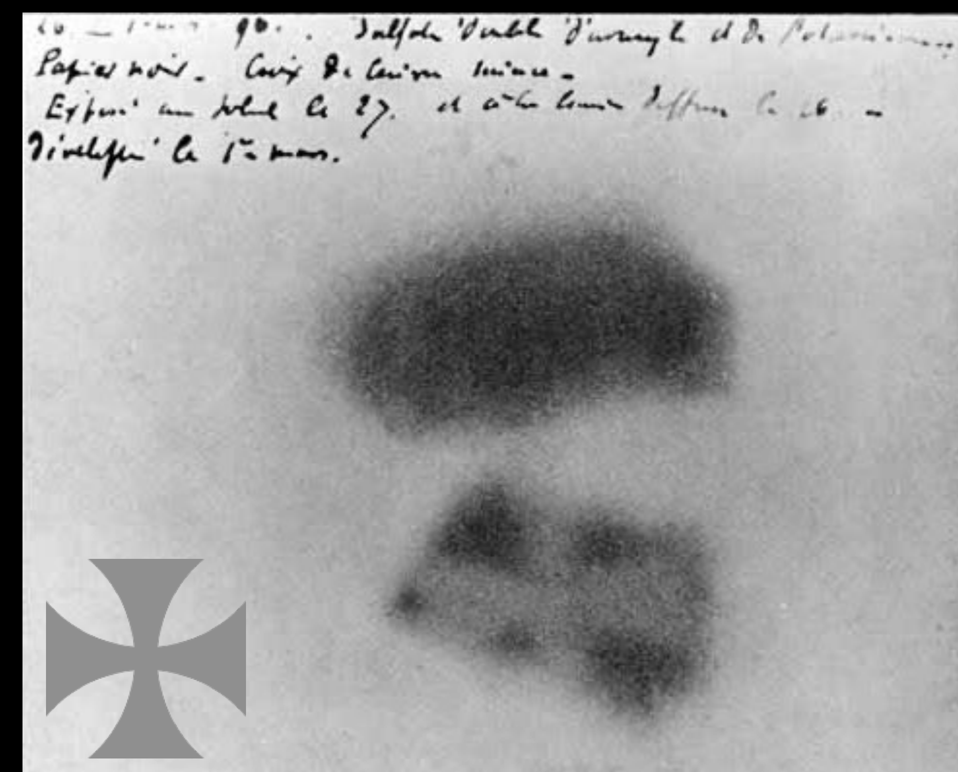
Enjoying their honeymoon (1895)



The Curies in 1895

Enjoying their honeymoon (1895)

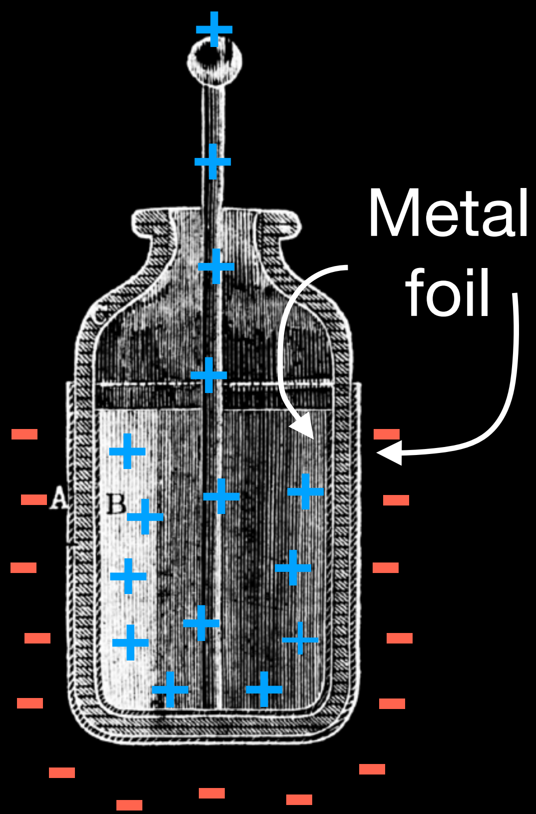
1896: Marie is looking for a doctoral thesis topic



How to quantify the strength of Becquerel’s radiation?

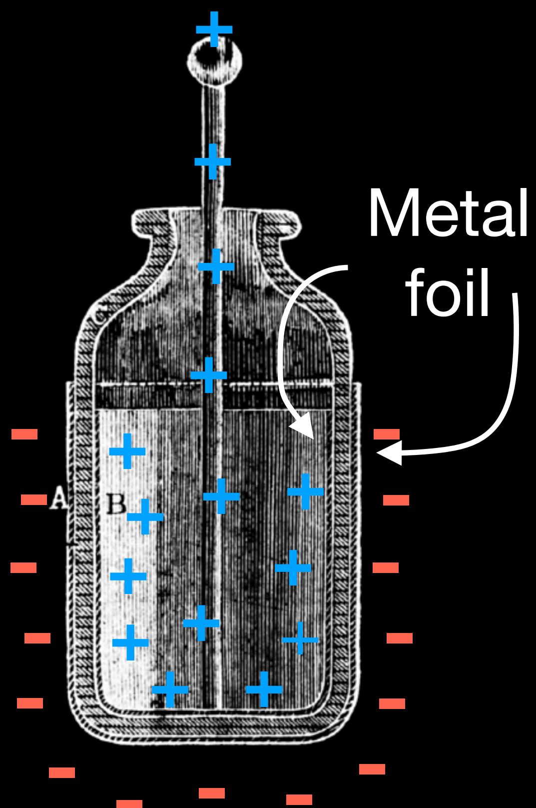
A connection with electricity

A connection with electricity



Leyden jar
(“Cylindrical condenser”)

A connection with electricity



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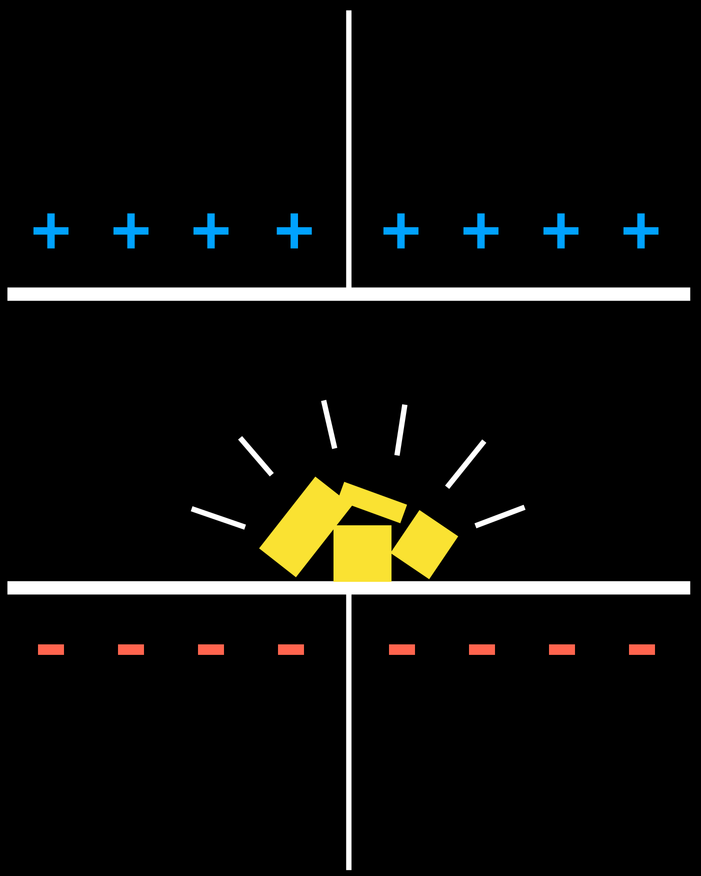
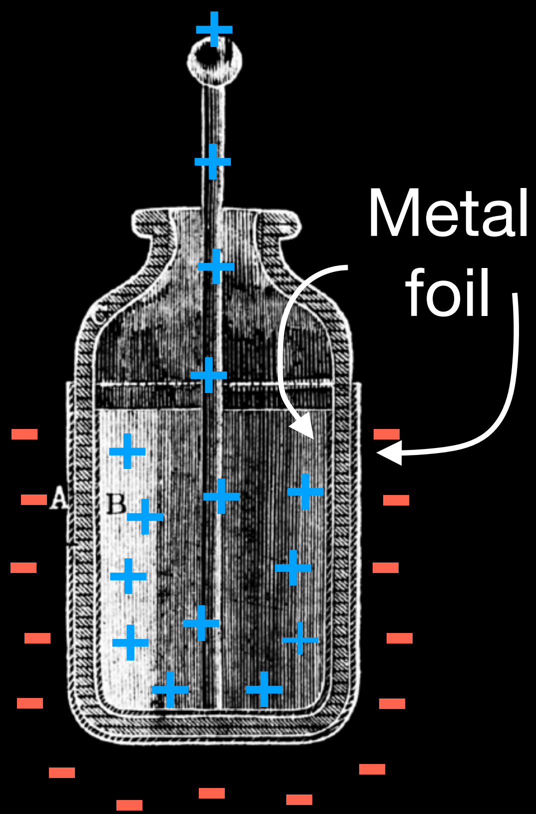


"Becquerel rays"
are "ionizing"

"Parallel-plate condenser"

A connection with electricity



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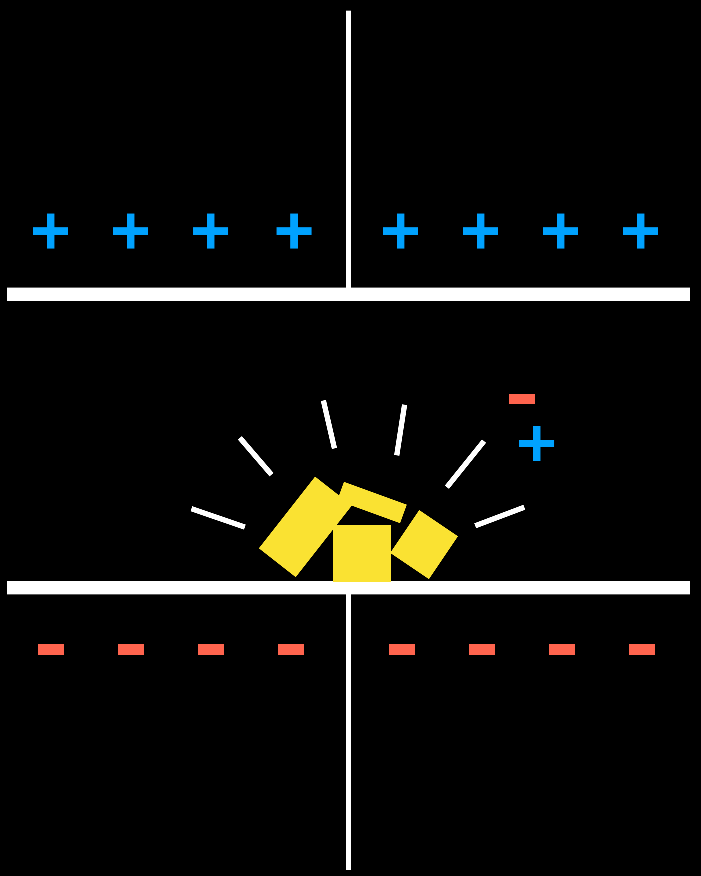

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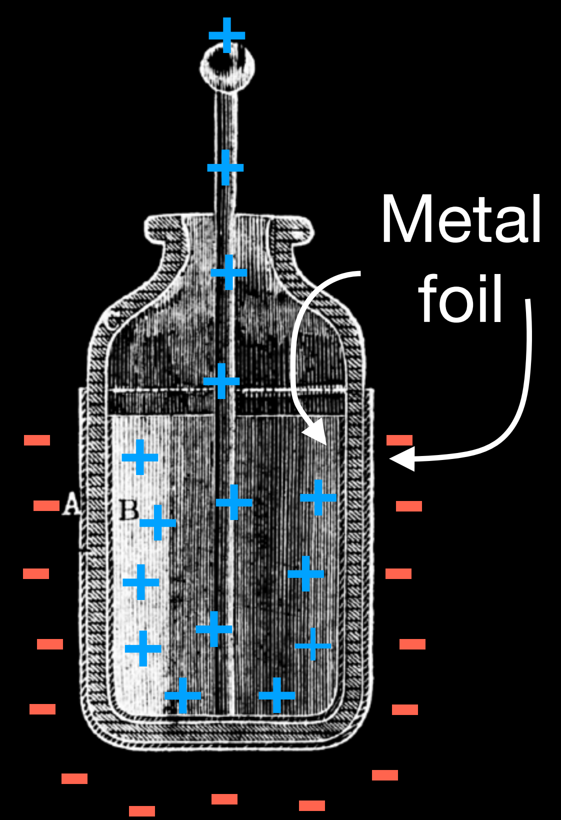

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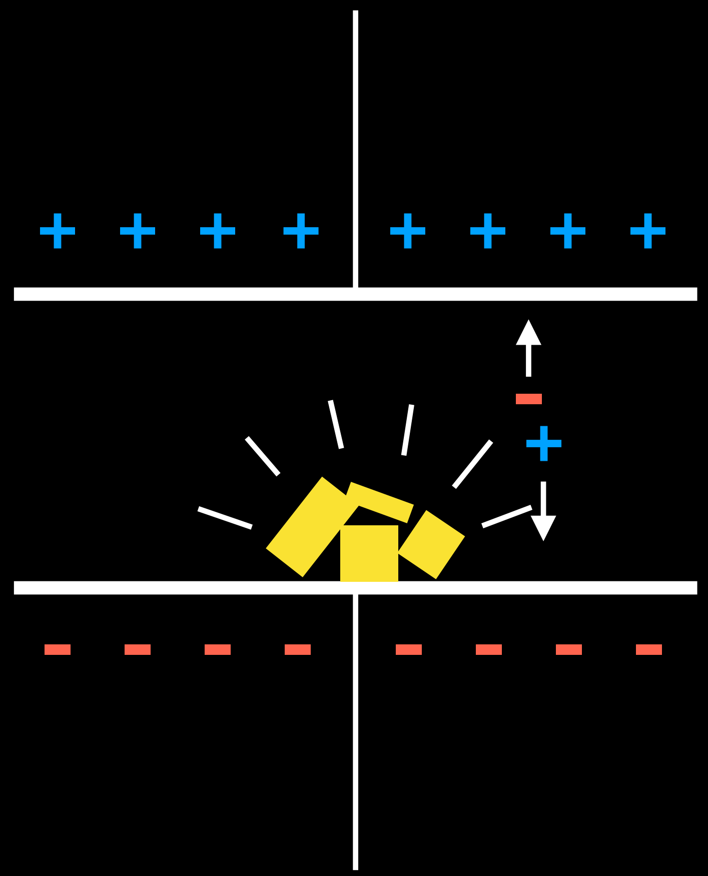

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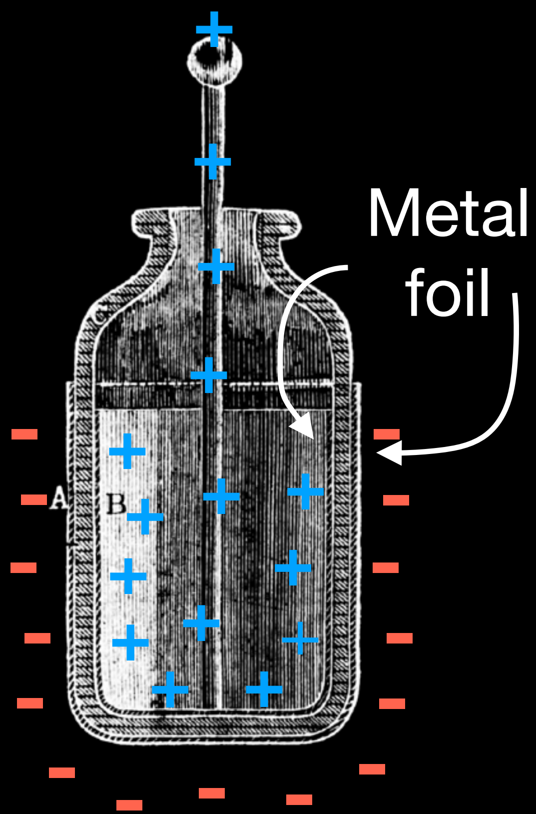

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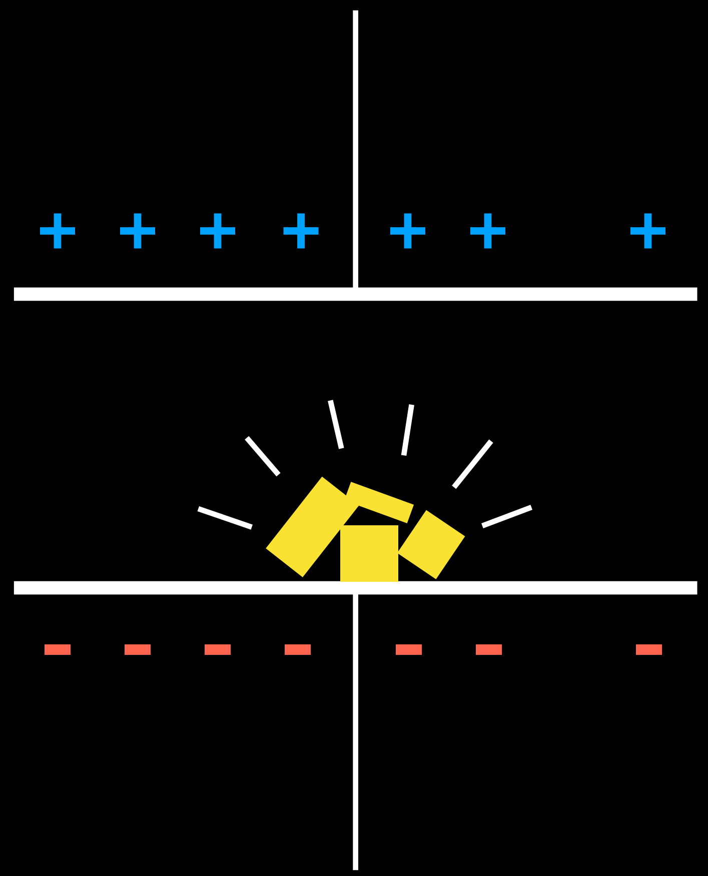

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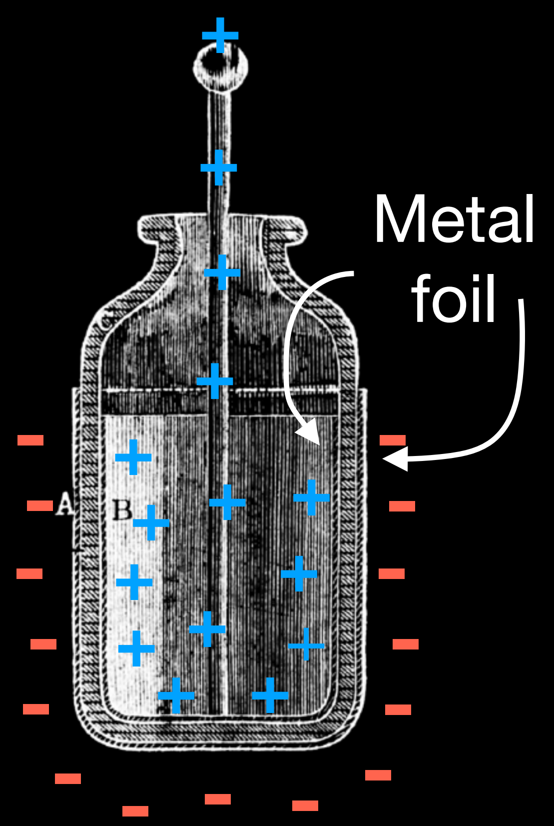

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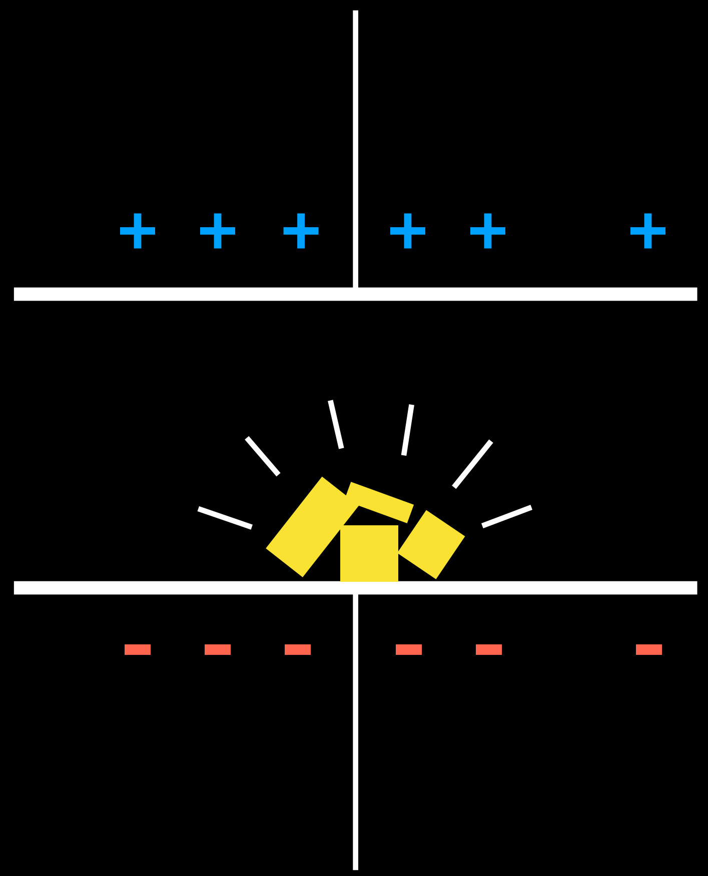

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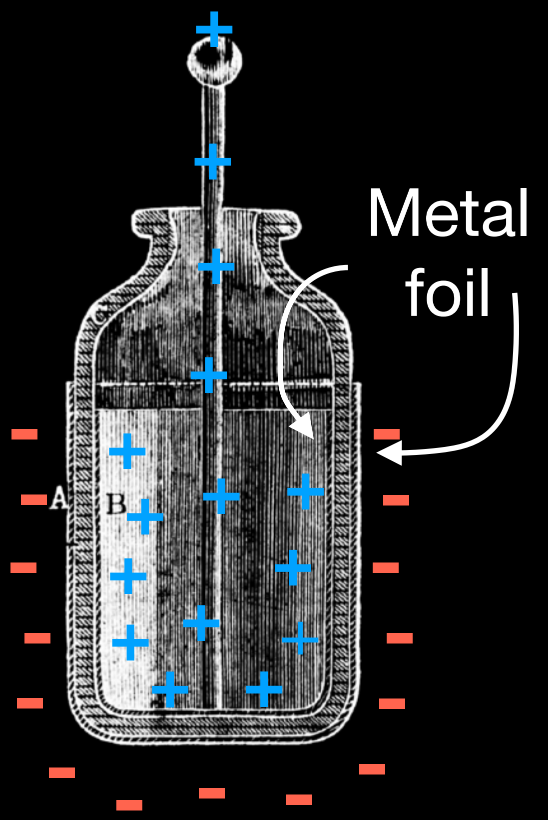

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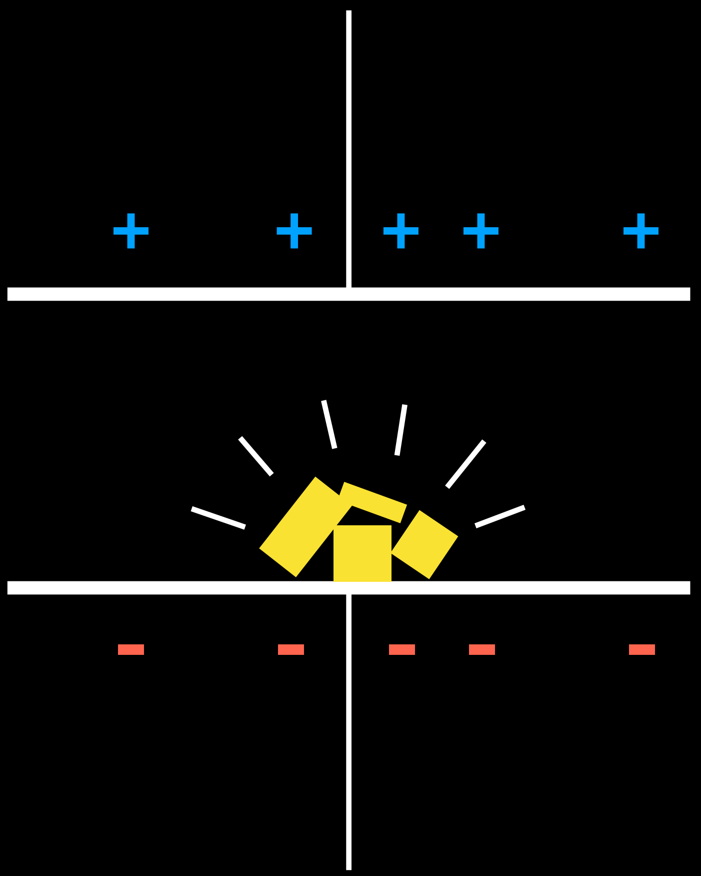
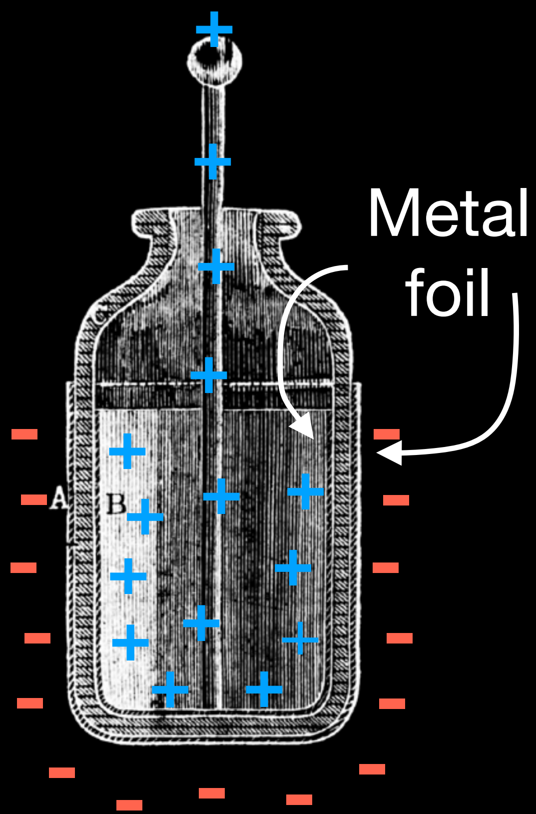


“Parallel-plate condenser”

A connection with electricity



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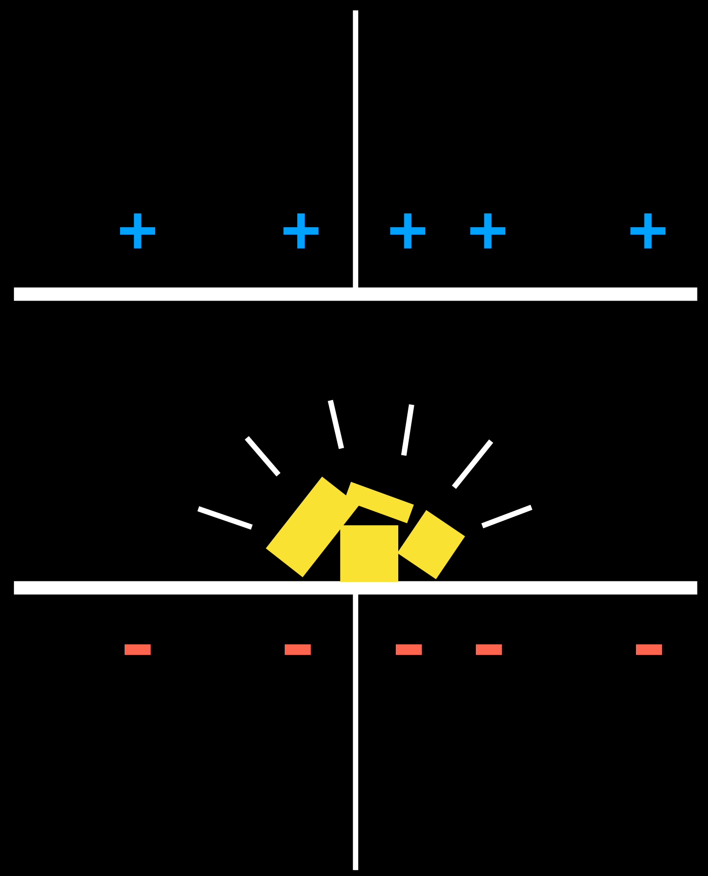
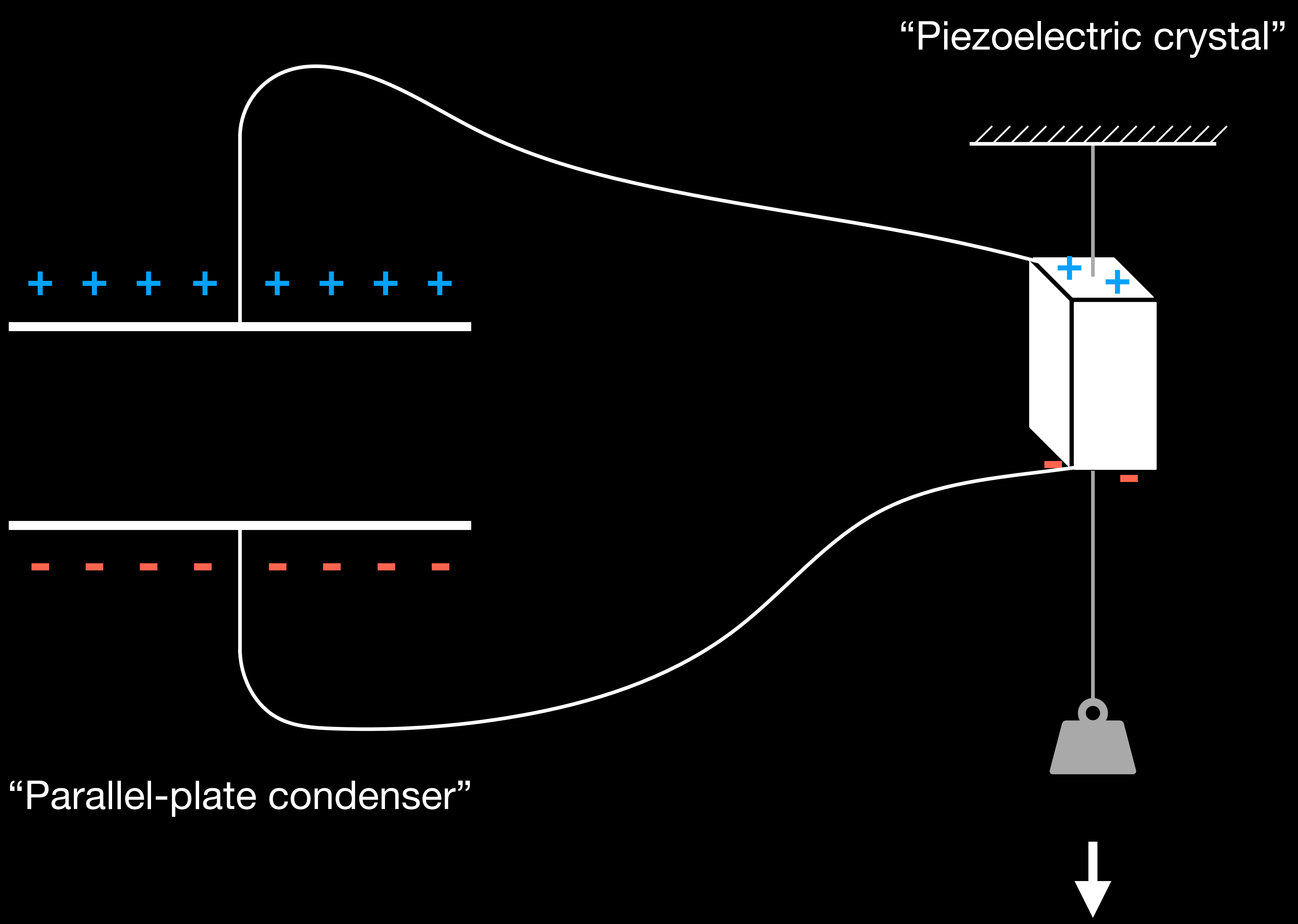


"Parallel-plate condenser"

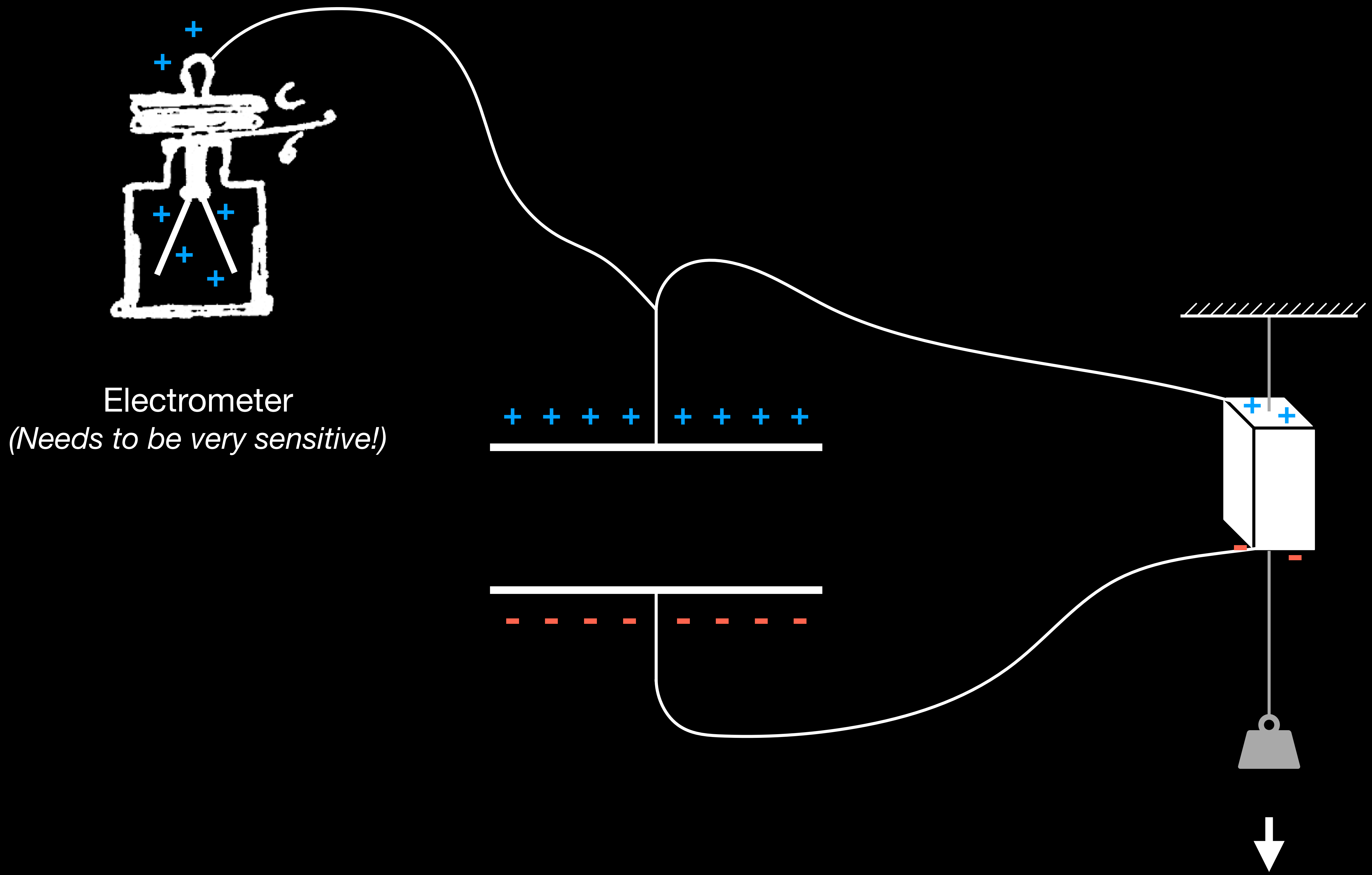
"Becquerel rays" gradually discharge the condenser

Very small! Need very precise experiments!

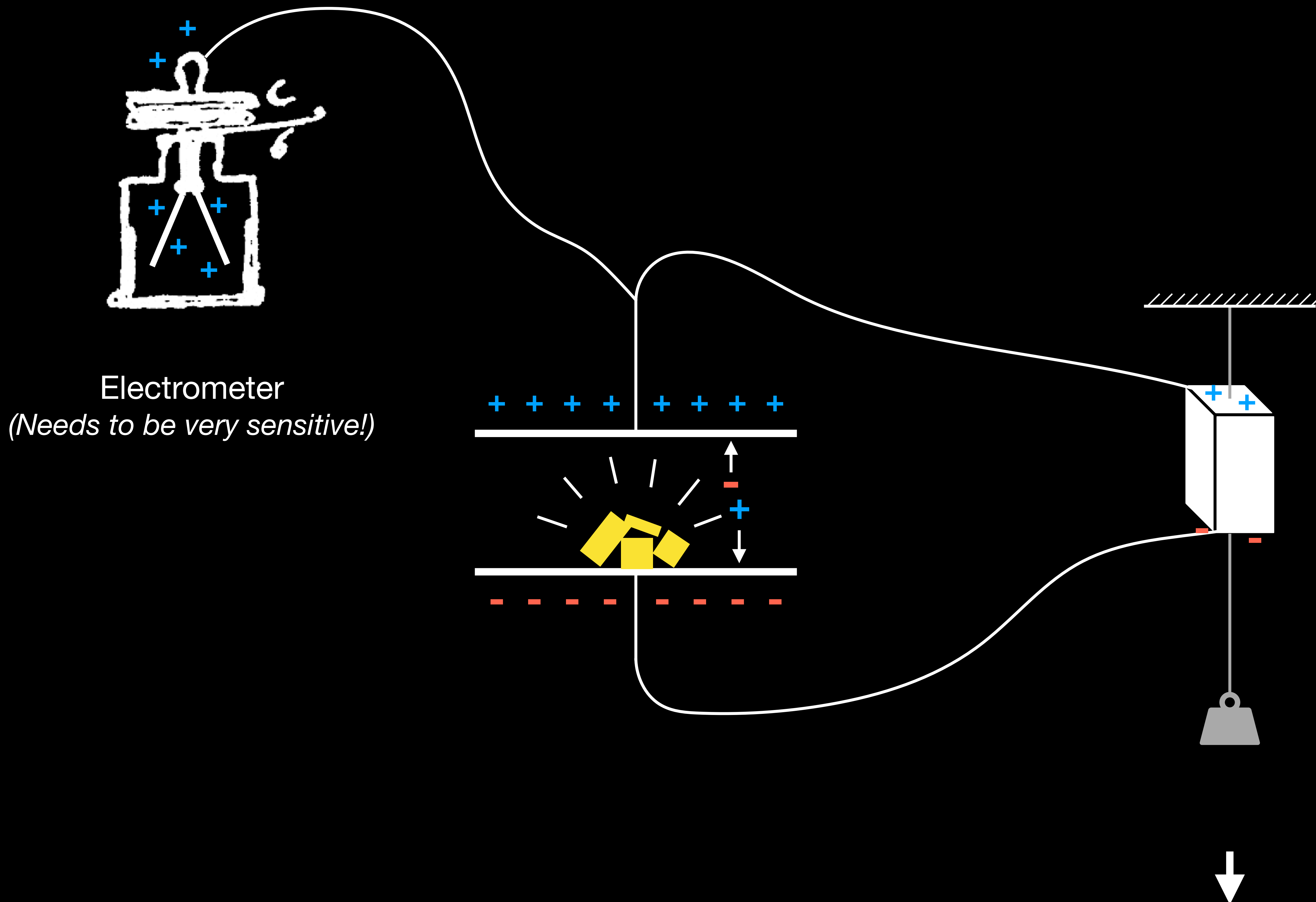
How to charge the condenser?



How to measure the discharge?

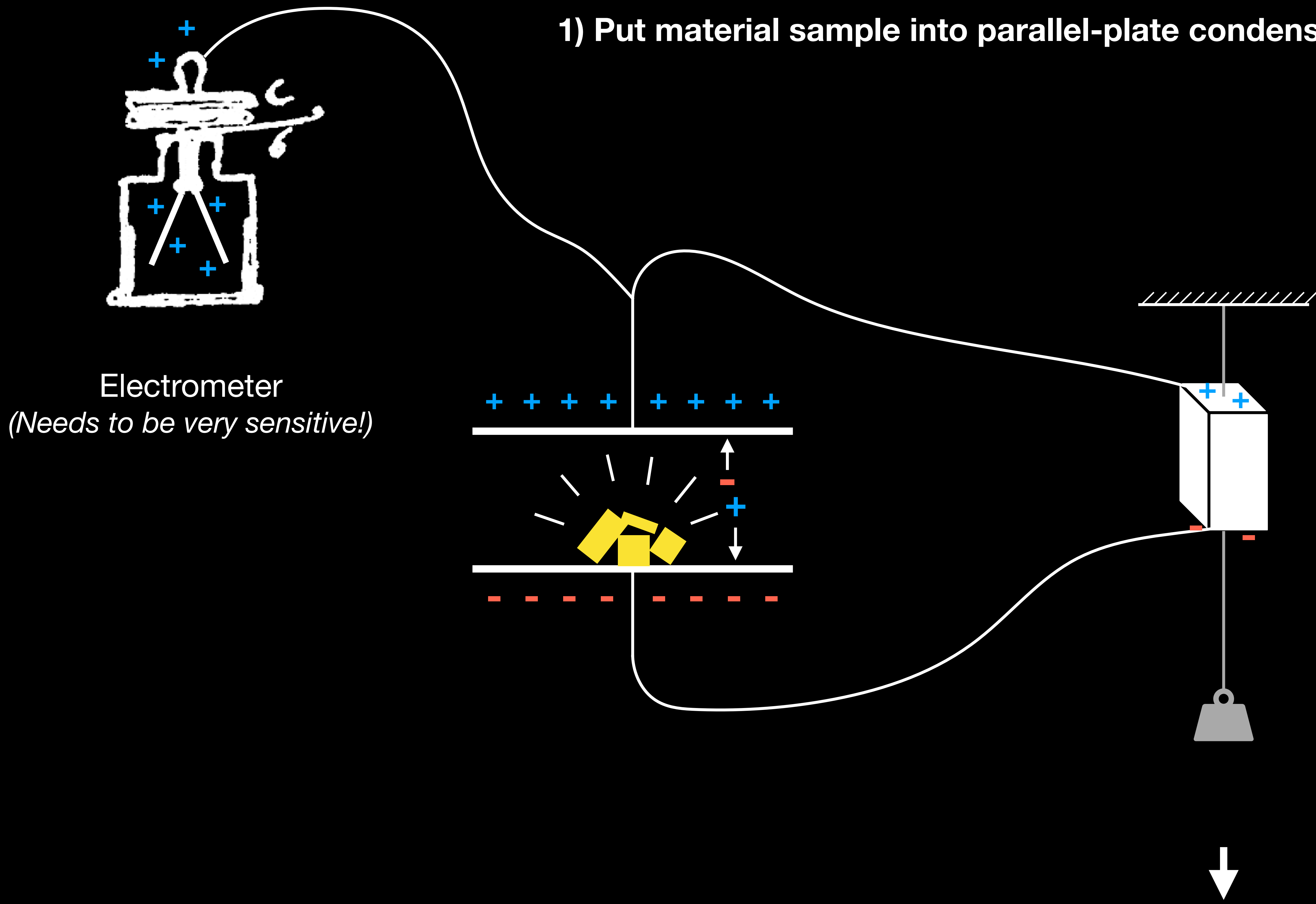


How to perform the experiment?



How to perform the experiment?

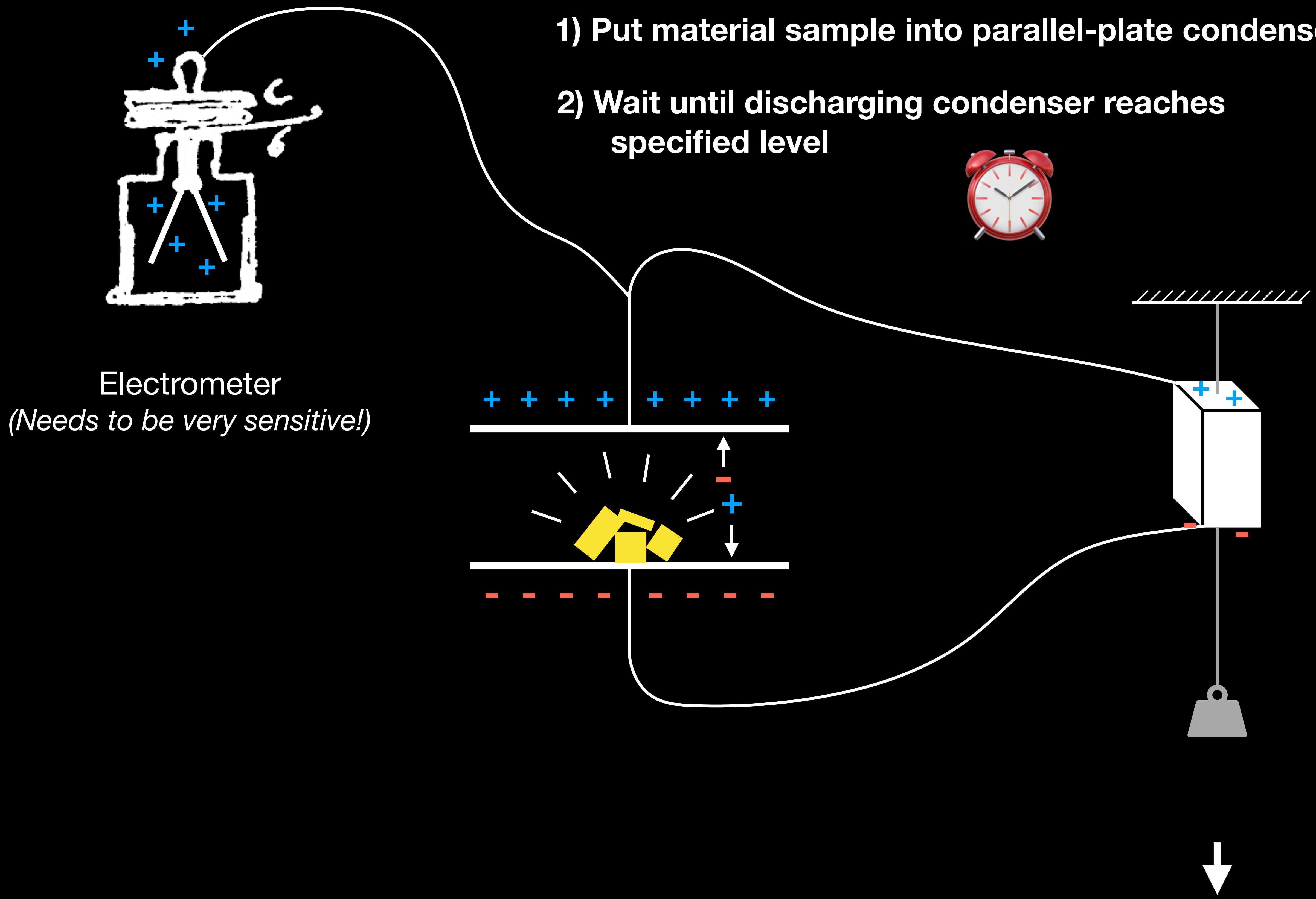
1) Put material sample into parallel-plate condenser



How to perform the experiment?

1) Put material sample into parallel-plate condenser

2) Wait until discharging condenser reaches specified level



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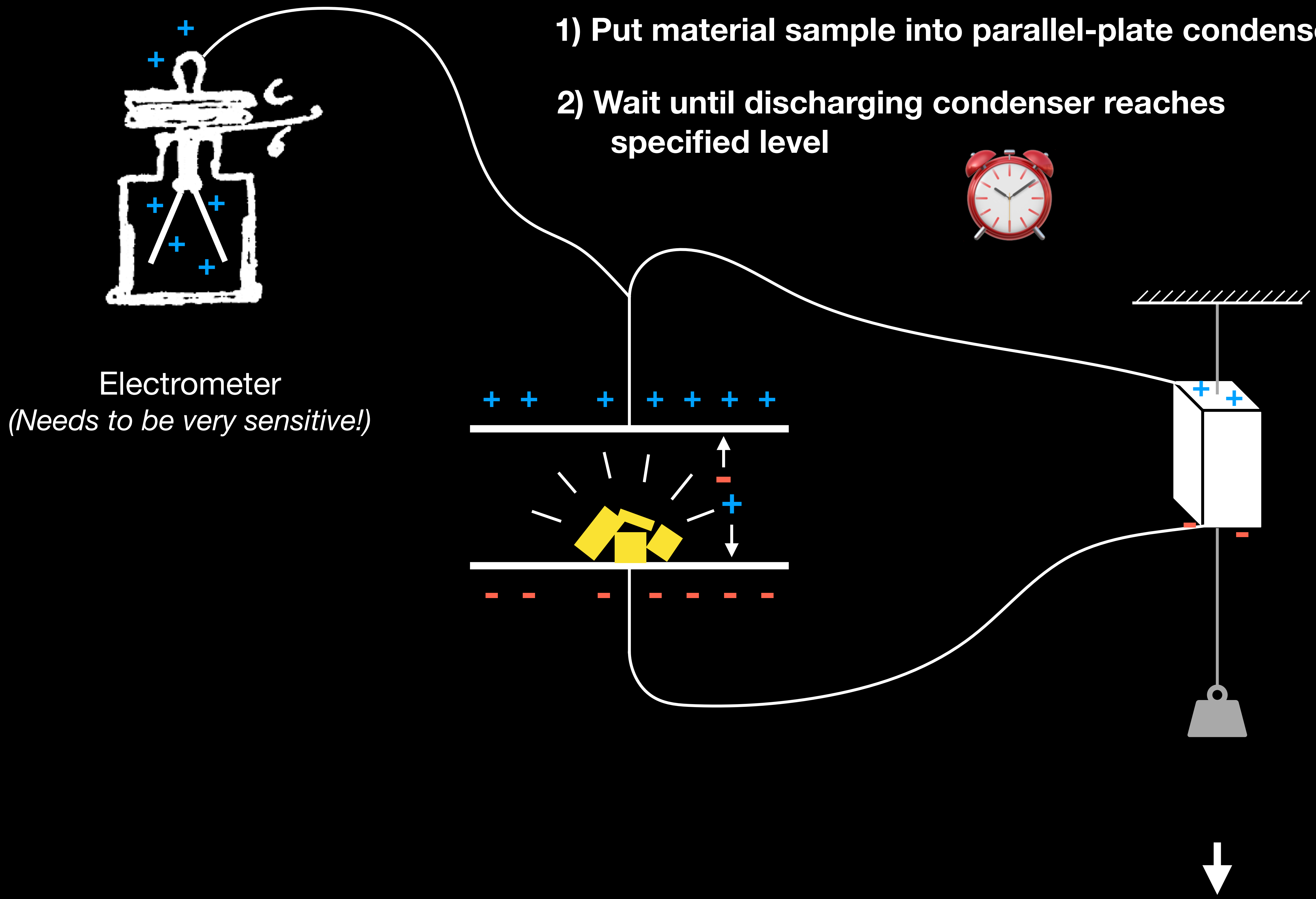

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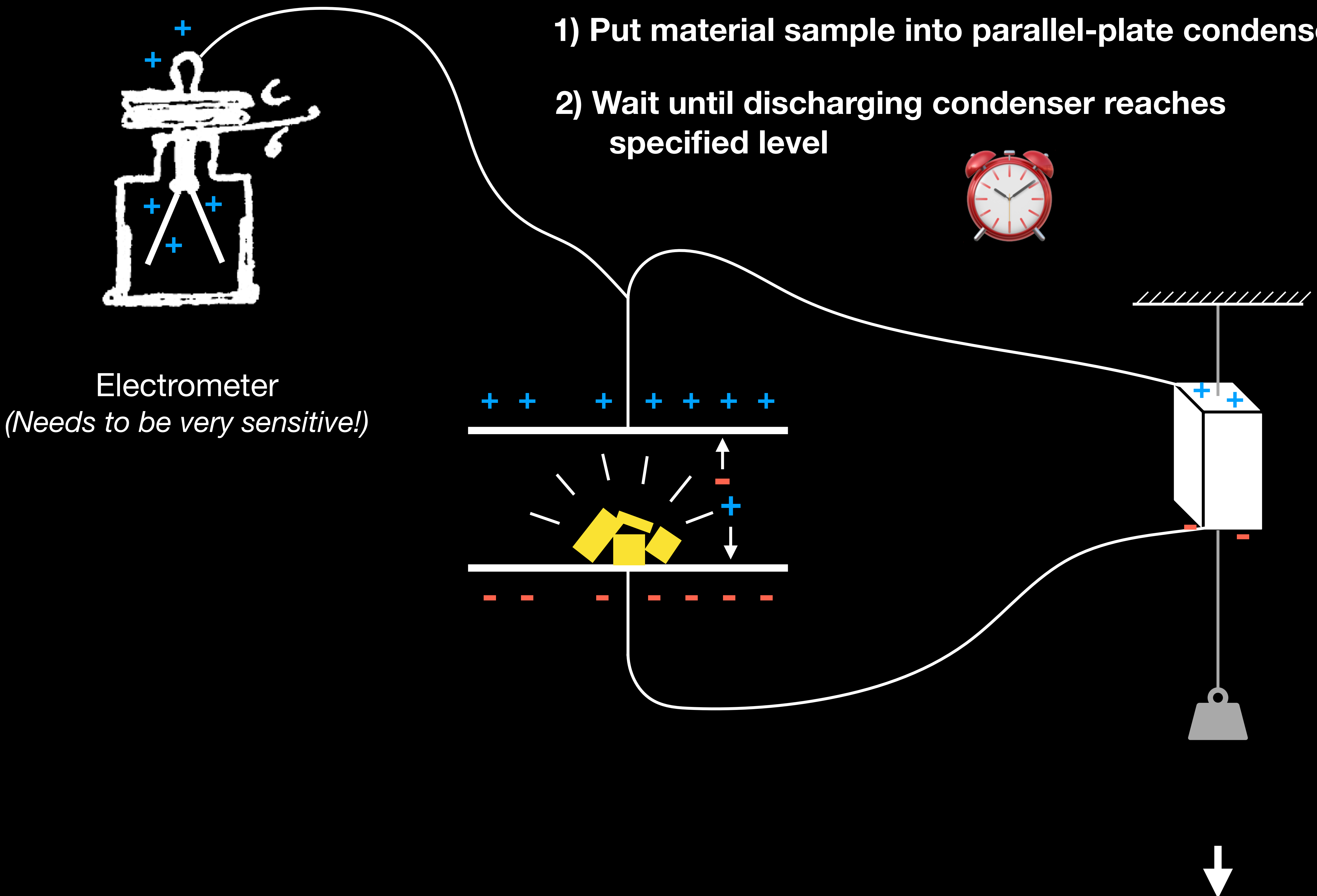

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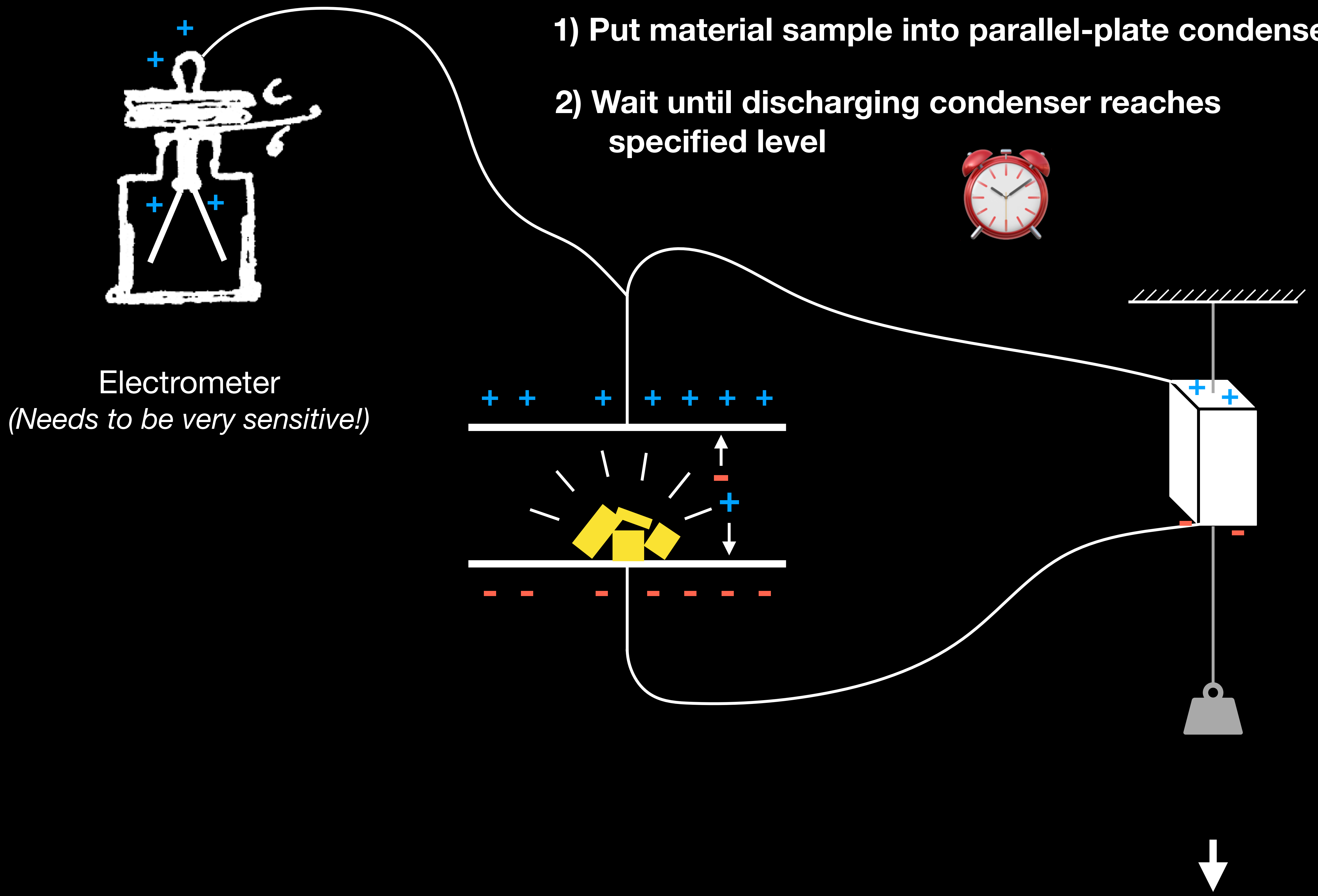

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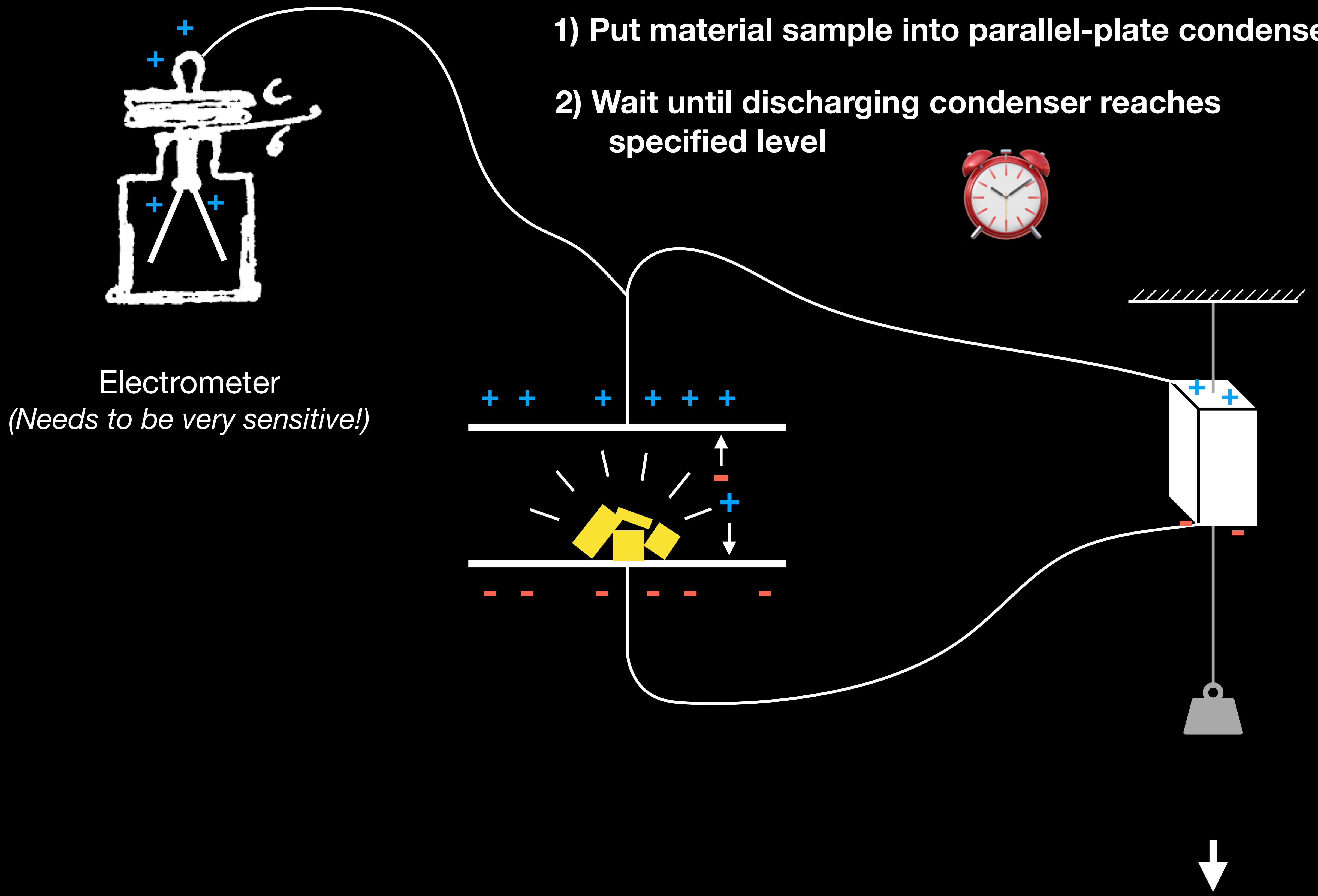

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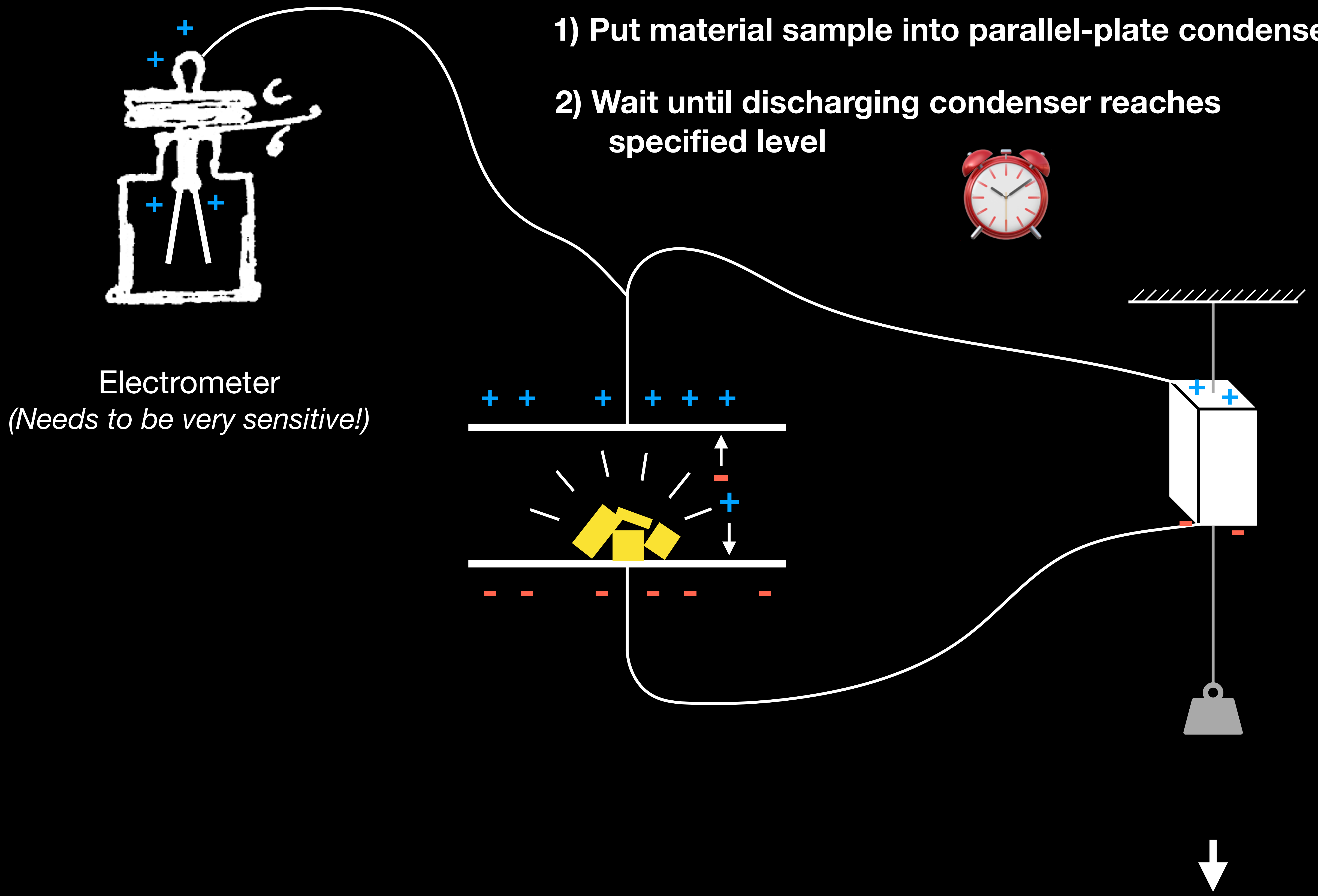

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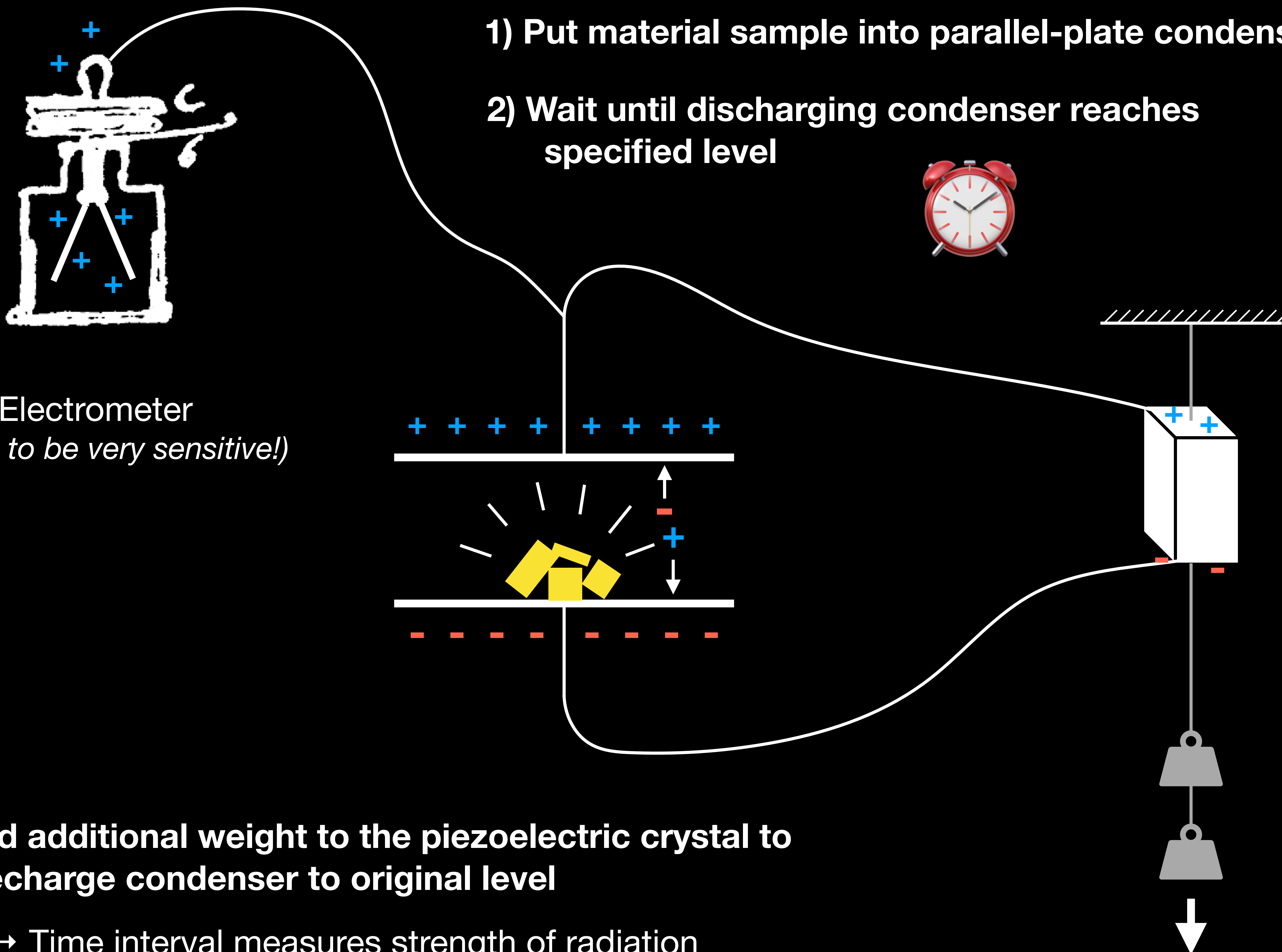
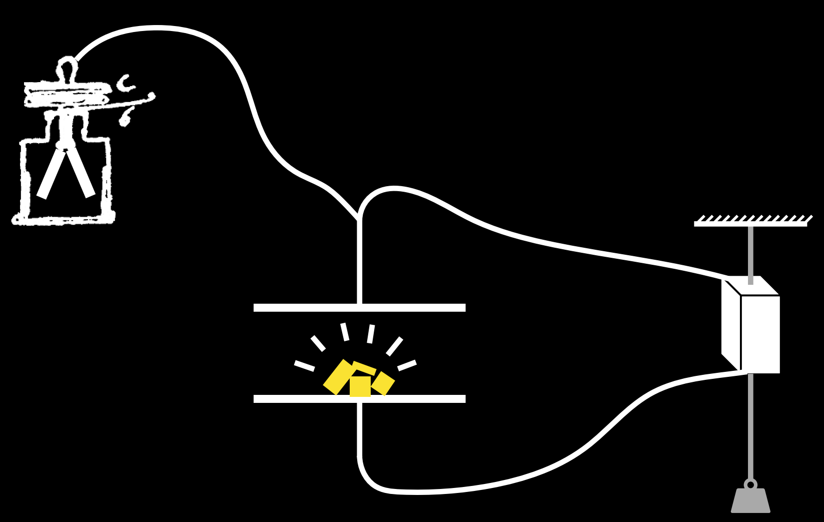


3) Add additional weight to the piezoelectric crystal to recharge condenser to original level

→ Time interval measures strength of radiation

The real experiment

The real plate condenser



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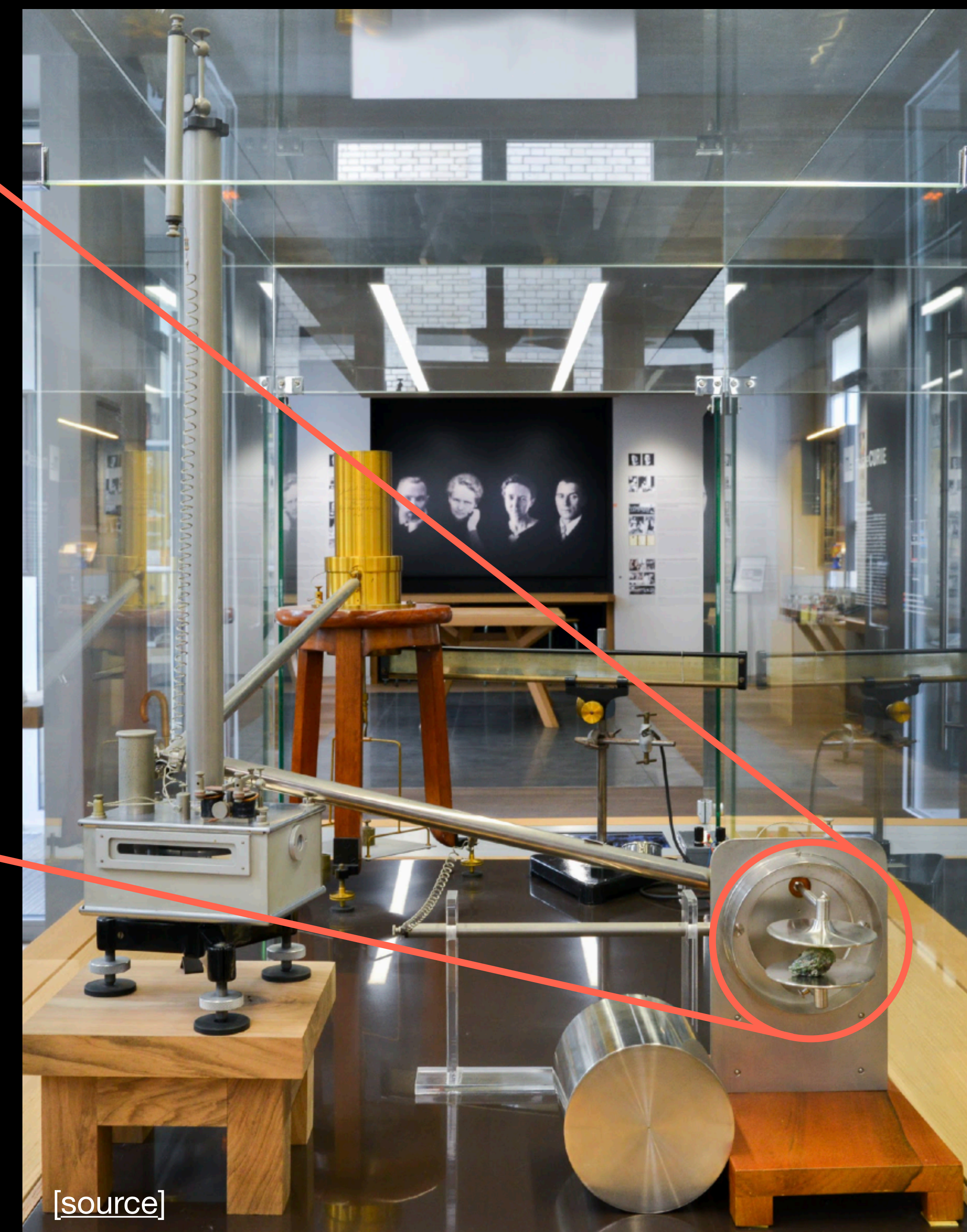

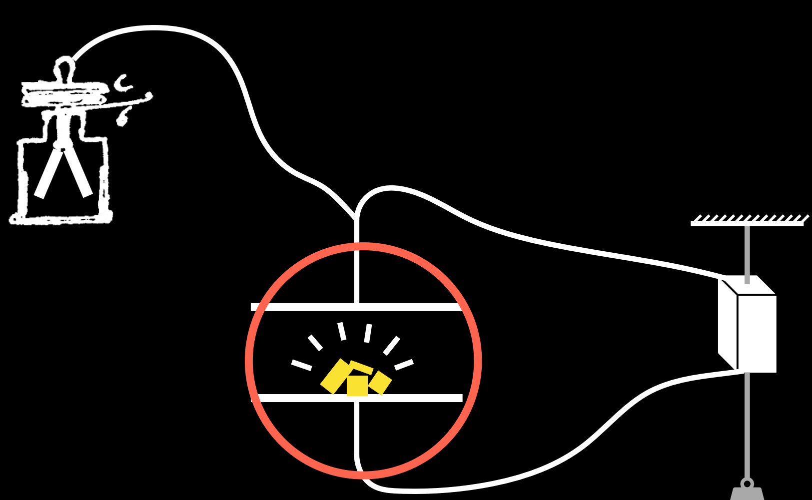

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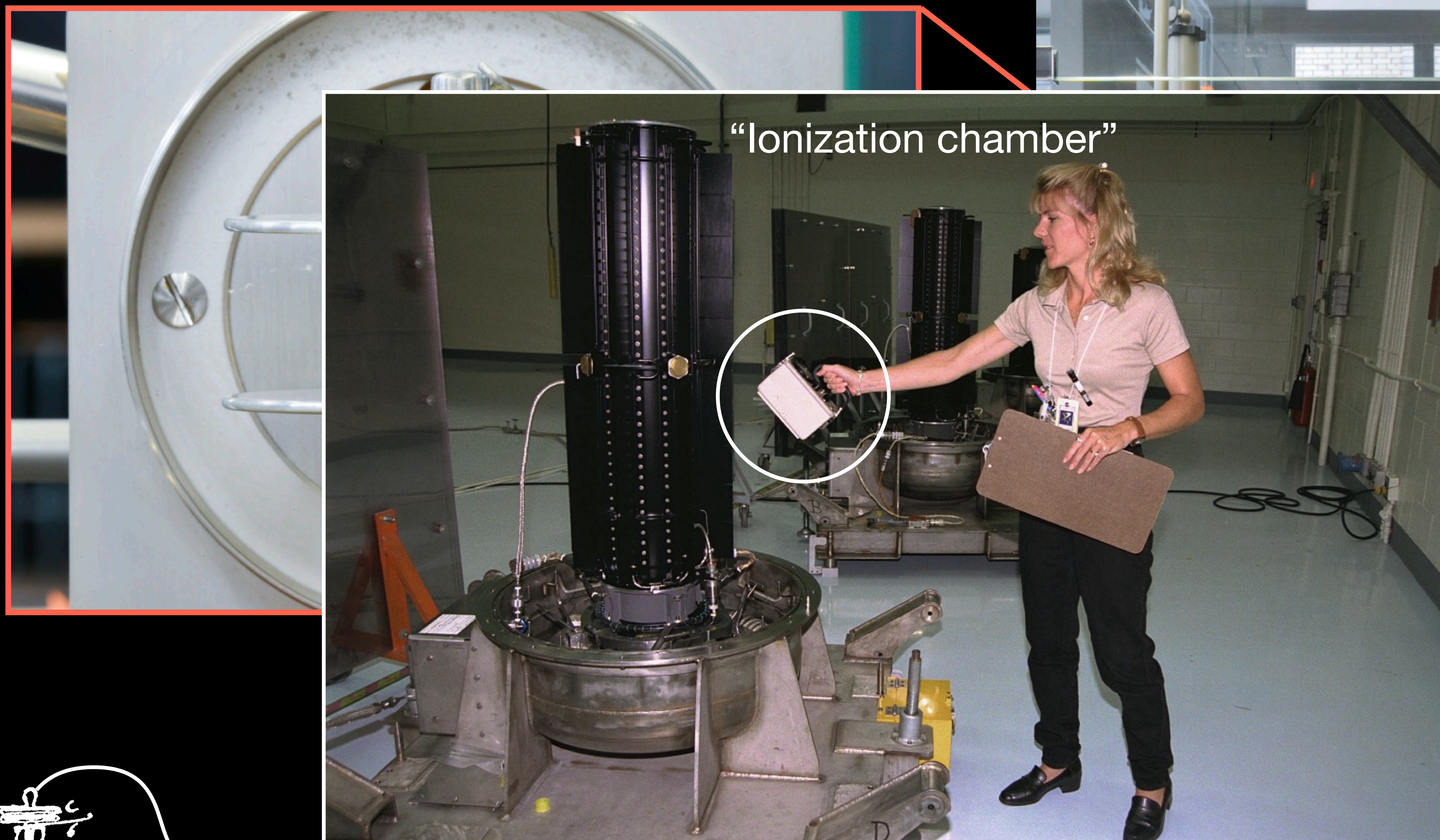
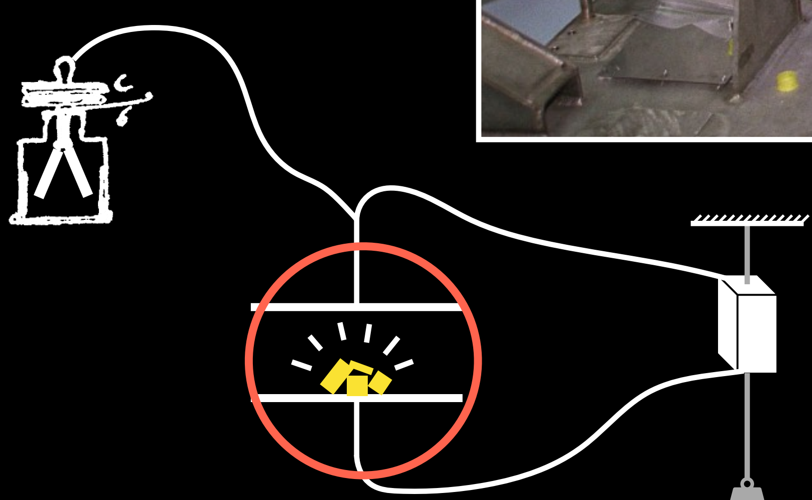
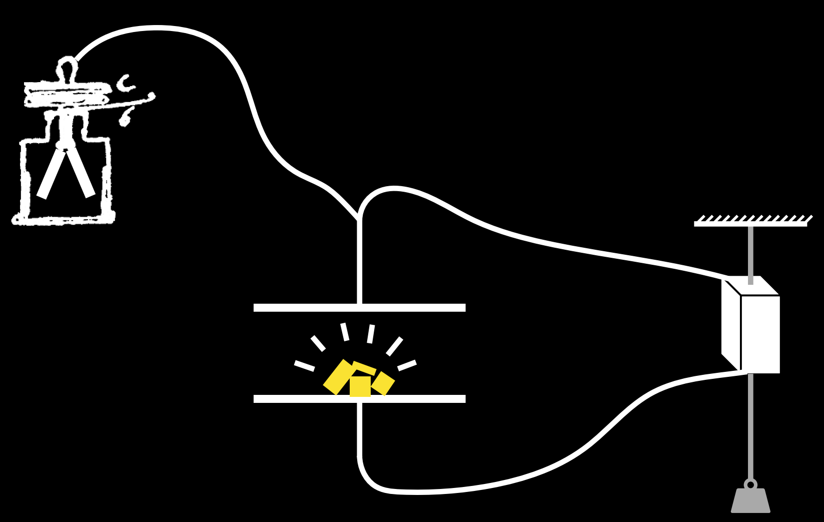




The real piezoelectric crystal



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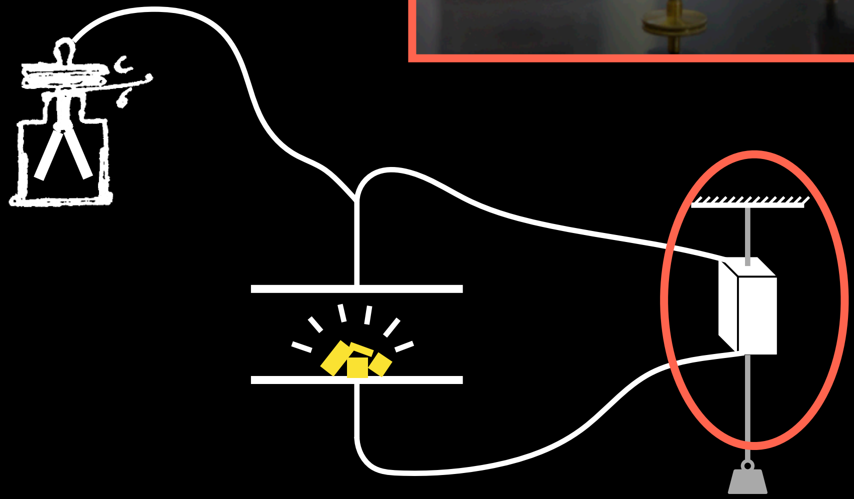
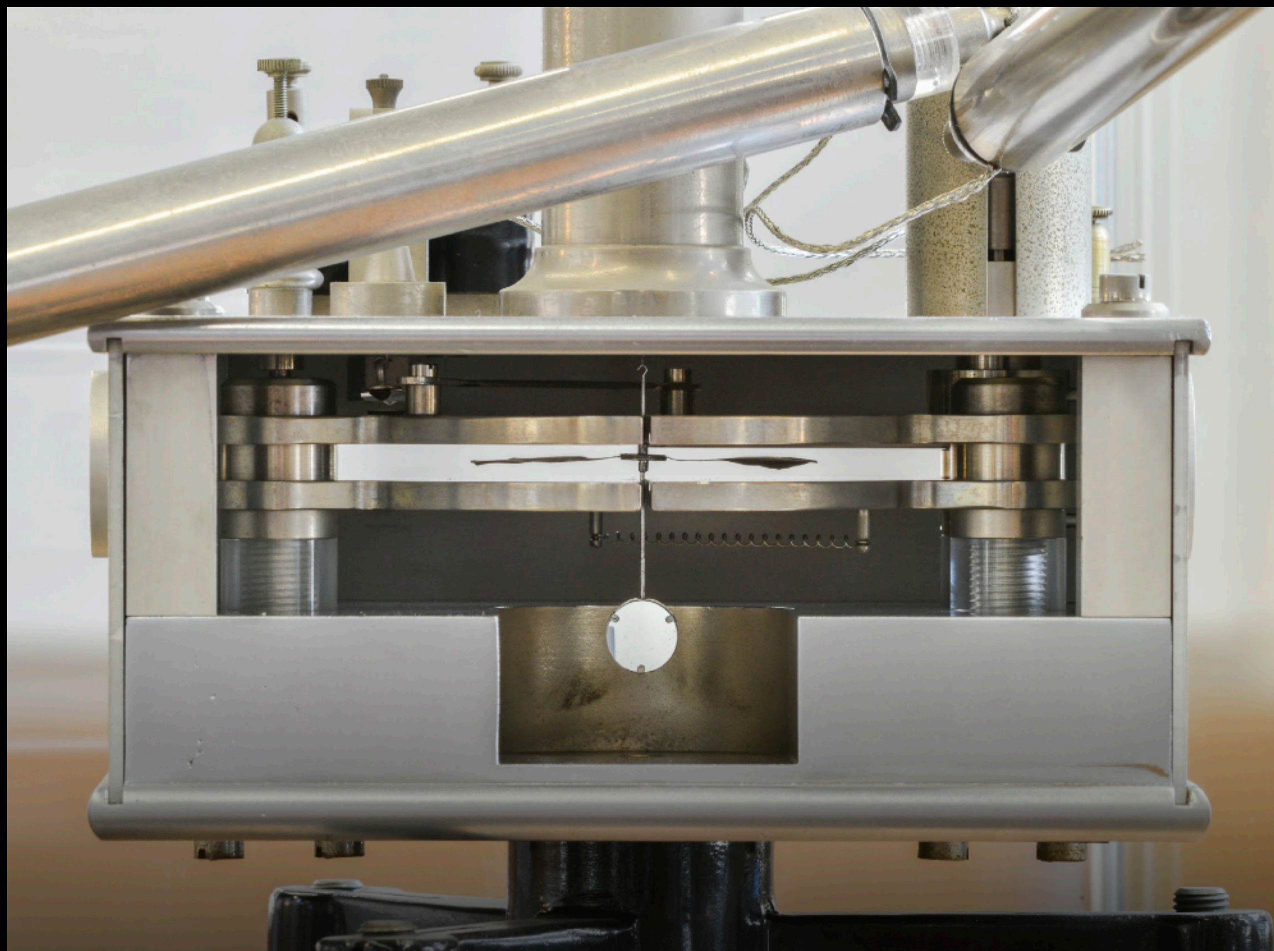


Pierre's precision electrometer



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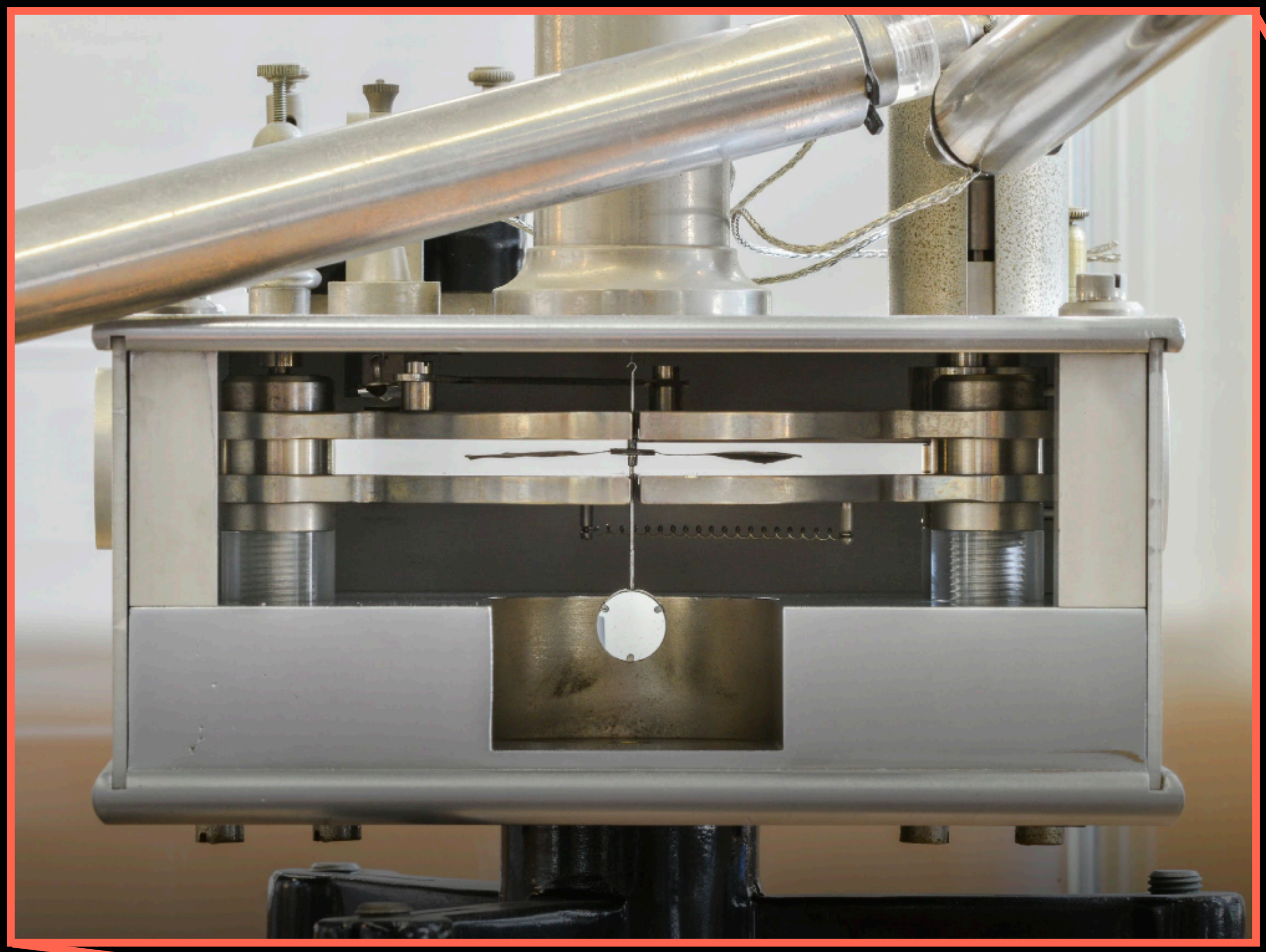

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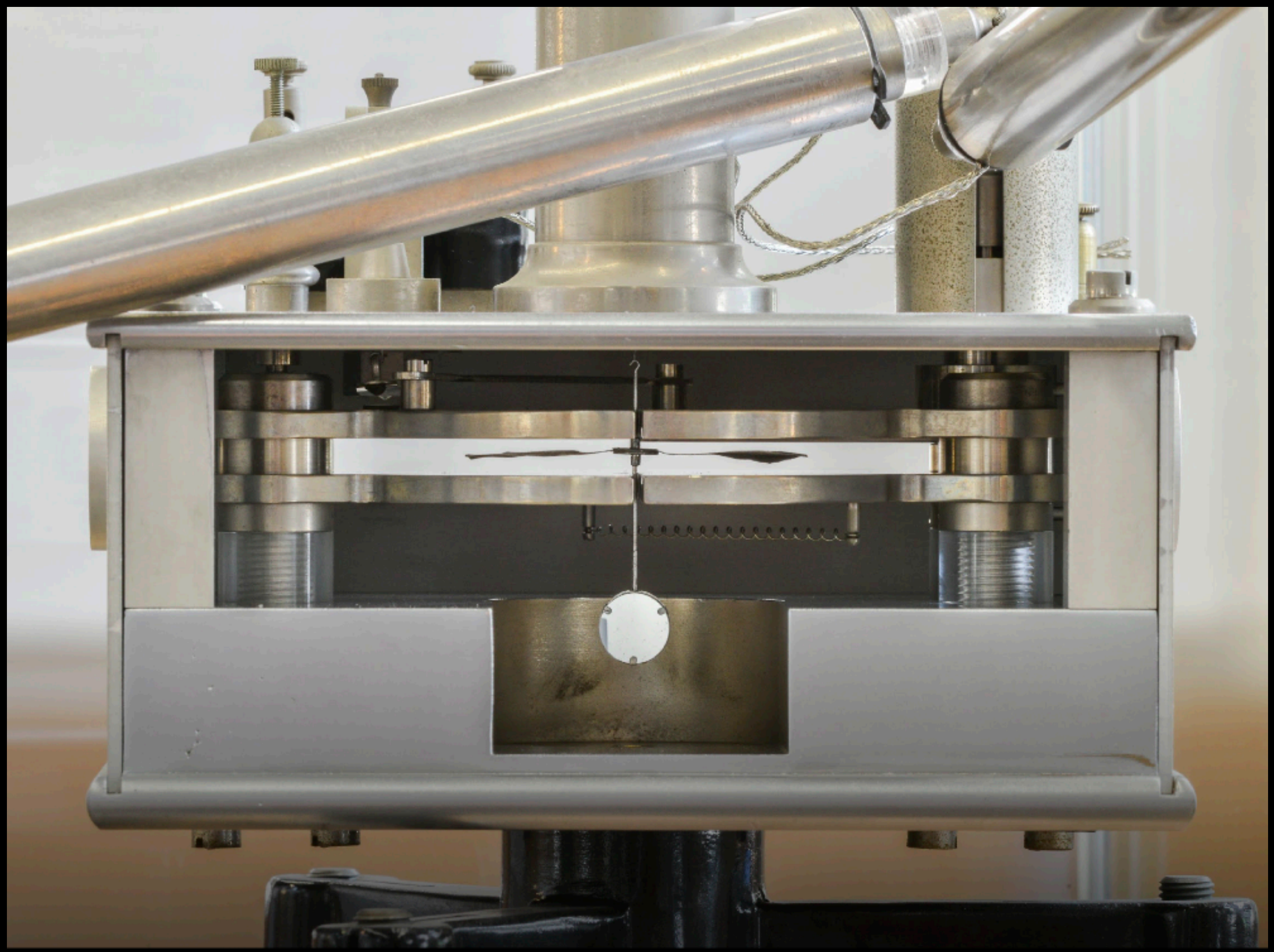


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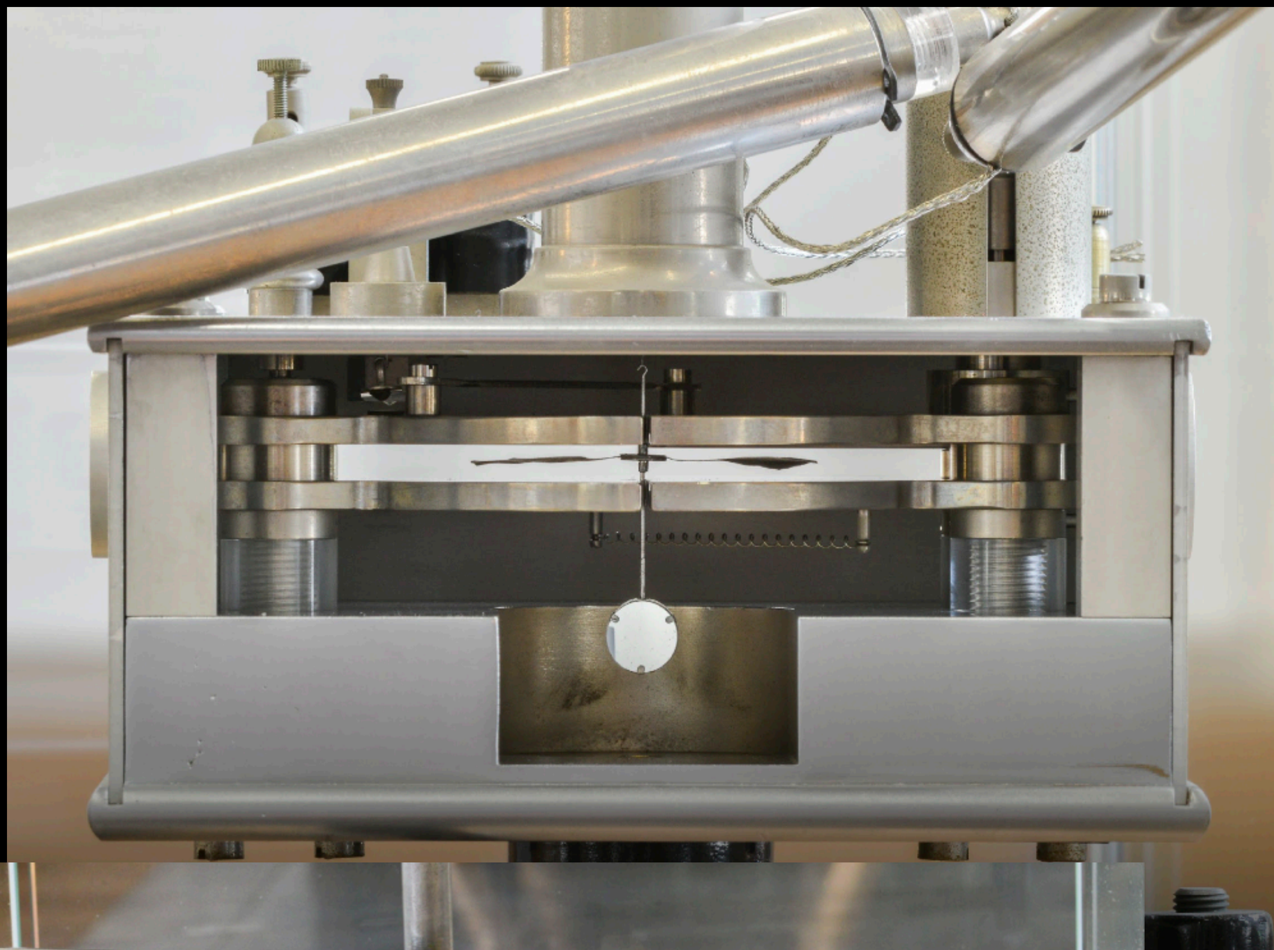

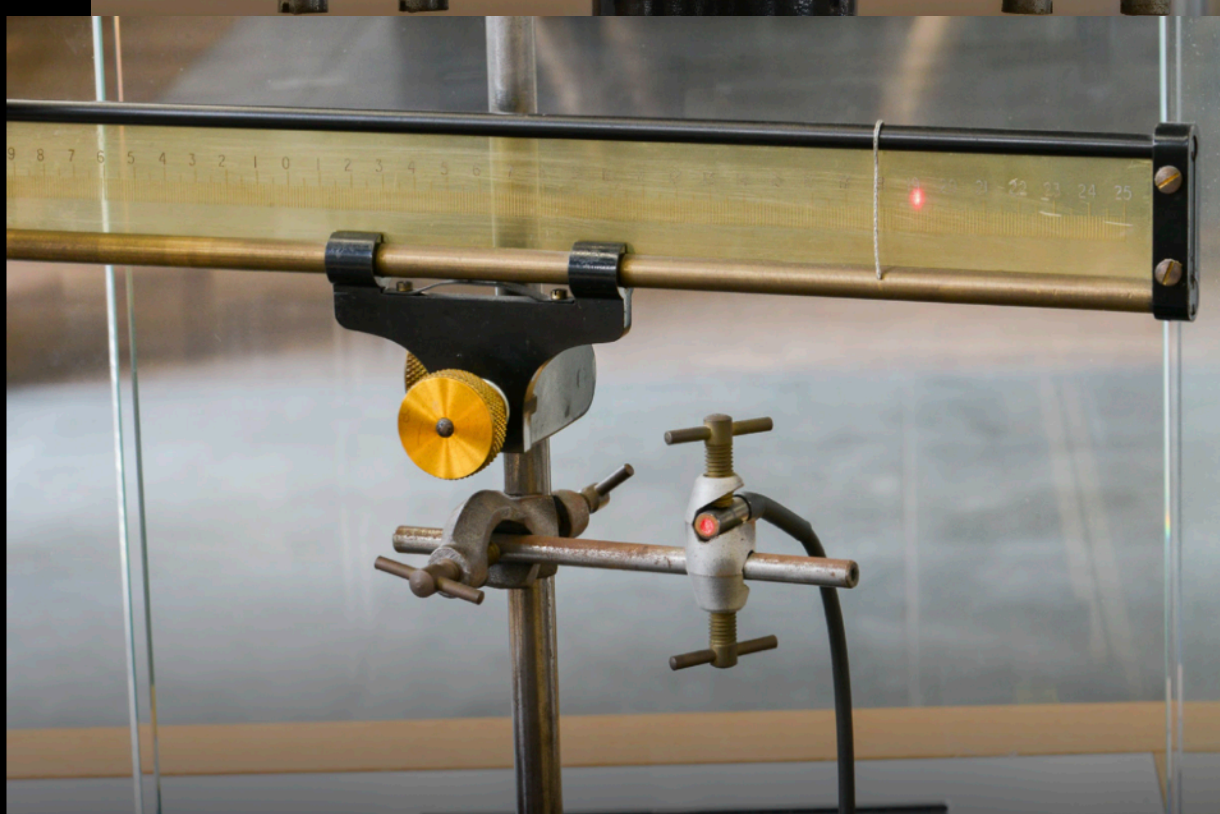

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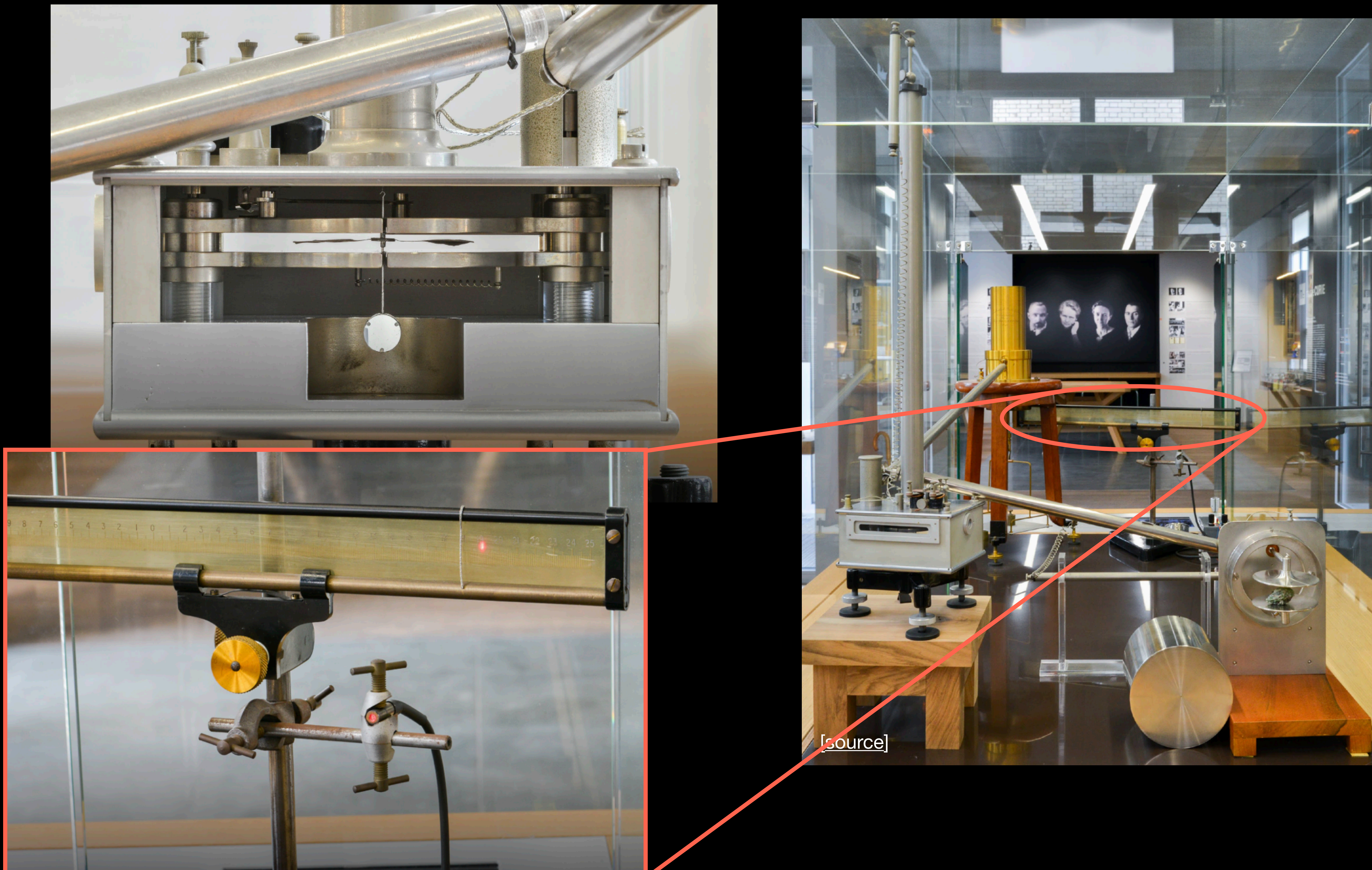

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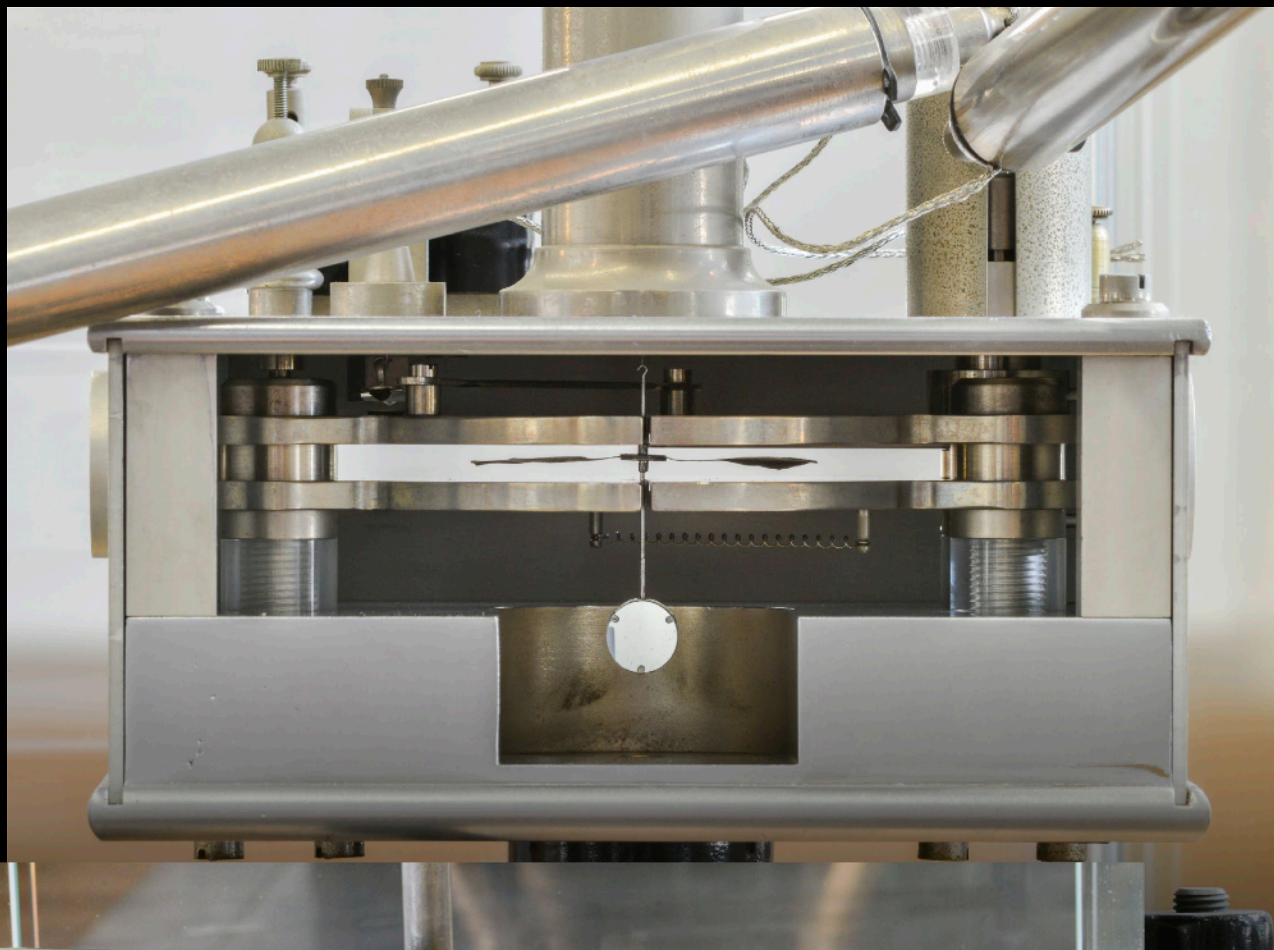

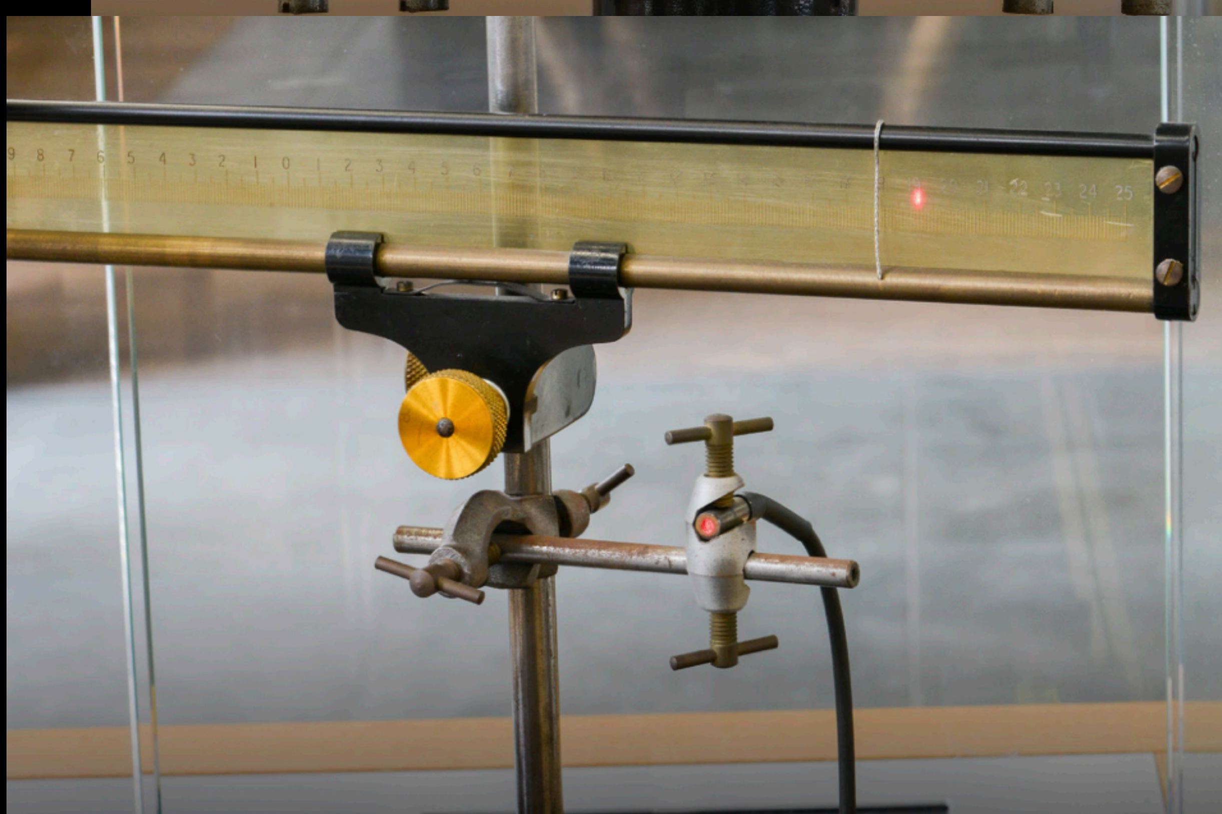

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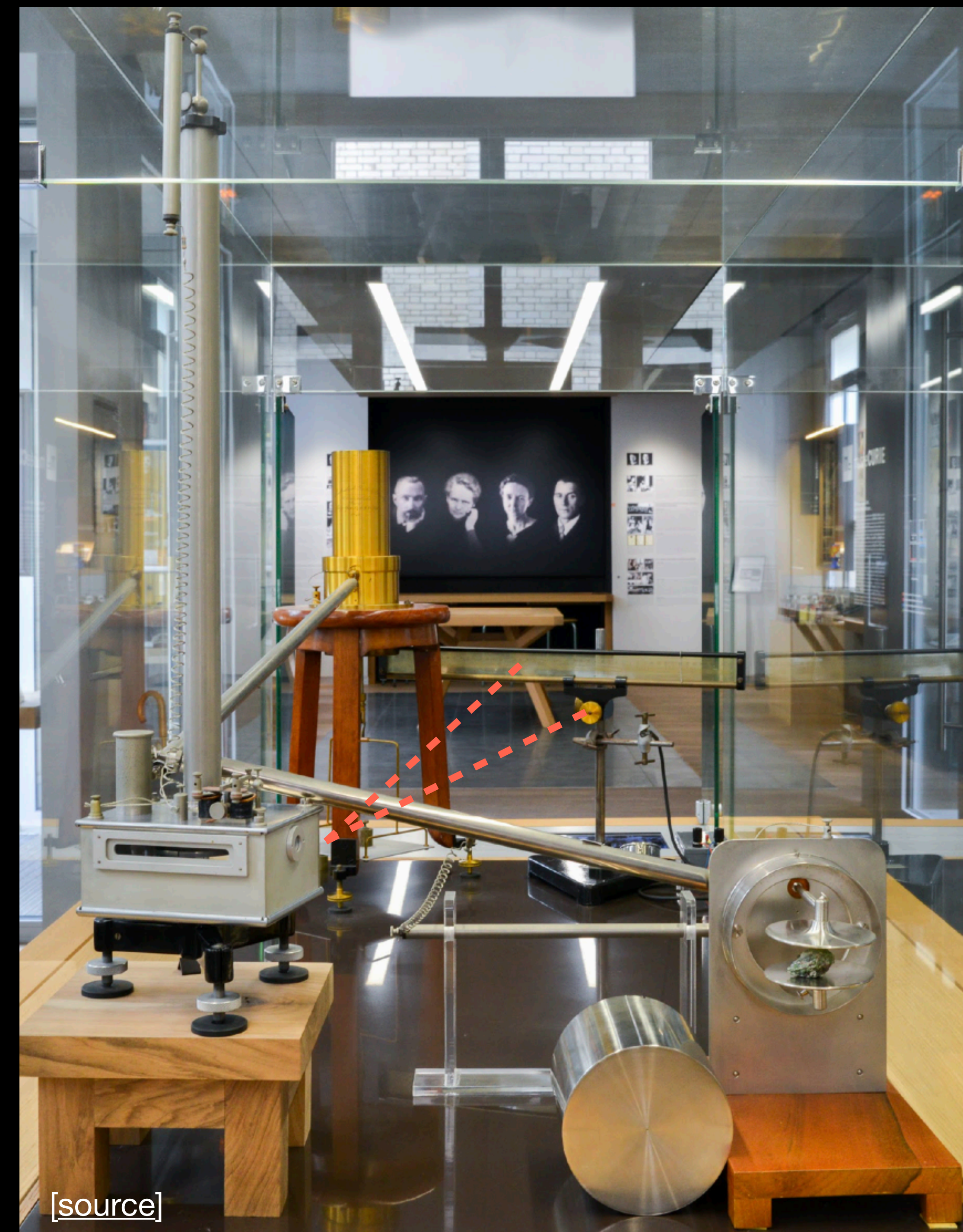

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Taking the measurements

Taking the measurements

Testing different materials

Uranium and thorium minerals are the most “active”

	Ampères.
Uranium légèrement carburé	24×10^{-12}
Oxyde noir d'uranium U^2O^5	27 »
Oxyde vert d'uranium U^3O^8	18 »
Uranates d'ammonium, de potassium, de sodium, environ	12 »
Acide uranique hydraté	6 »
Azotate d'uranyle, sulfate uraneux, sulfate d'uranyle et de potassium, environ	7 »
Chalcolite artificielle (phosphate de cuivre et d'uranyle)	9 »
Oxyde de thorium en couche de $0^{mm},25$ d'épaisseur	22 »
Oxyde de thorium en couche de 6^{mm} d'épaisseur	53 »
Sulfate de thorium	8 »
Pechblende de Johanngeorgenstadt	83 »
» de Cornwallis	16 »
» de Joachimsthal et de Pzibran	67 »
Chalcolite naturelle	52 »
Autunite	27 »
Thorites diverses	de 2 à 14 »
Orangite	20 »
Samarskite	11 »
Fergusonite, monazite, xénotime, niobite, æschinite	de 3 à 7 »
Clèveïte très active.	

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*“I was struck by the fact that the activity of uranium and thorium compounds **appears to be an atomic property** of the element uranium and of the element thorium.”*

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Clèveïte très active.	

*“I was struck by the fact that the activity of uranium and thorium compounds **appears to be an atomic property** of the element uranium and of the element thorium.”*

“The activity is not destroyed by either physical changes of state or chemical transformations.”

Testing different materials

Uranium and thorium minerals are the most “active”

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Uranium légèrement carburé		24×10^{-12}
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Oxyde vert d'uranium U^3O^8		18 »
Uranates d'ammonium, de potassium, de sodium, environ		12 »
Acide uranique hydraté		6 »
Azotate d'uranyle, sulfate uraneux, sulfate d'uranyle et de potassium, environ		7 »
Chalcolite artificielle (phosphate de cuivre et d'uranyle)		9 »
Oxyde de thorium en couche de $0^{mm},25$ d'épaisseur		22 »
Oxyde de thorium en couche de 6^{mm} d'épaisseur		53 »
Sulfate de thorium		8 »
Pechblende de Johanngeorgenstadt		83 »
» de Cornwallis		16 »
» de Joachimsthal et de Pzibran		67 »
Chalcolite naturelle		52 »
Autunite		27 »
Thorites diverses	de 2 à	14 »
Orangite		20 »
Samarskite		11 »
Fergusonite, monazite, xénotime, niobite, æschinite	de 3 à	7 »
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Uranium and thorium minerals are the most “active”

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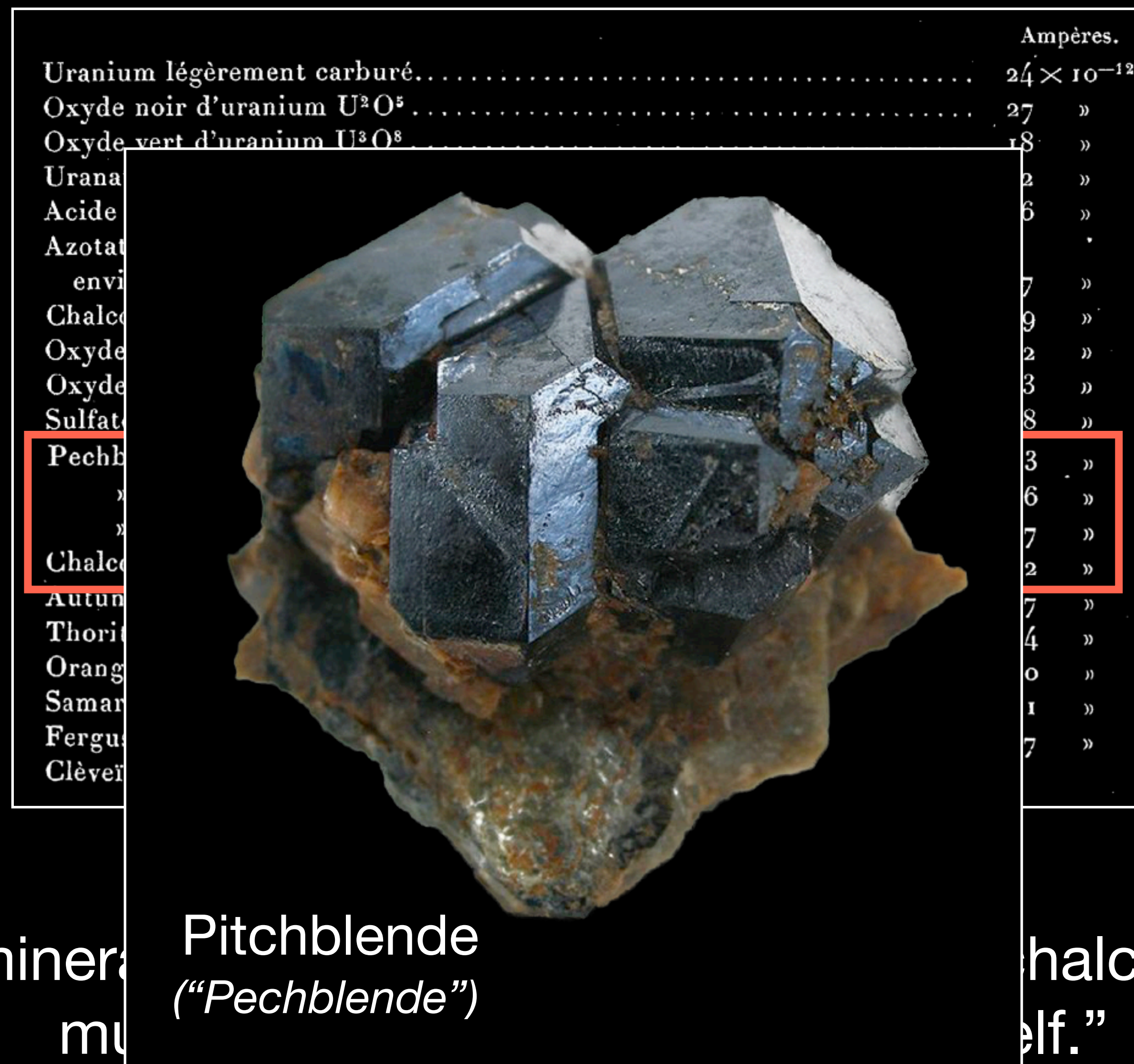

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→ “Radioactive” materials

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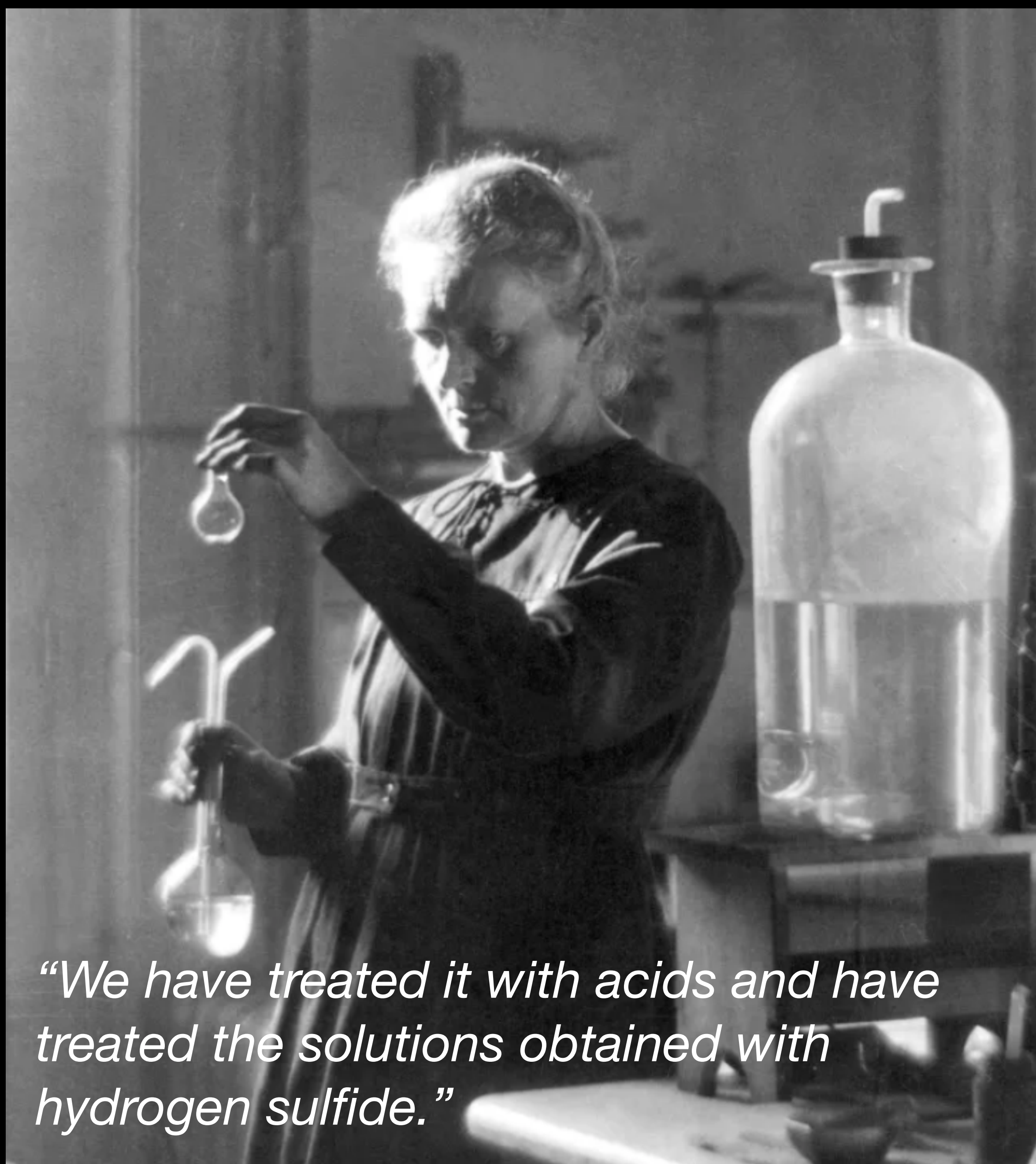

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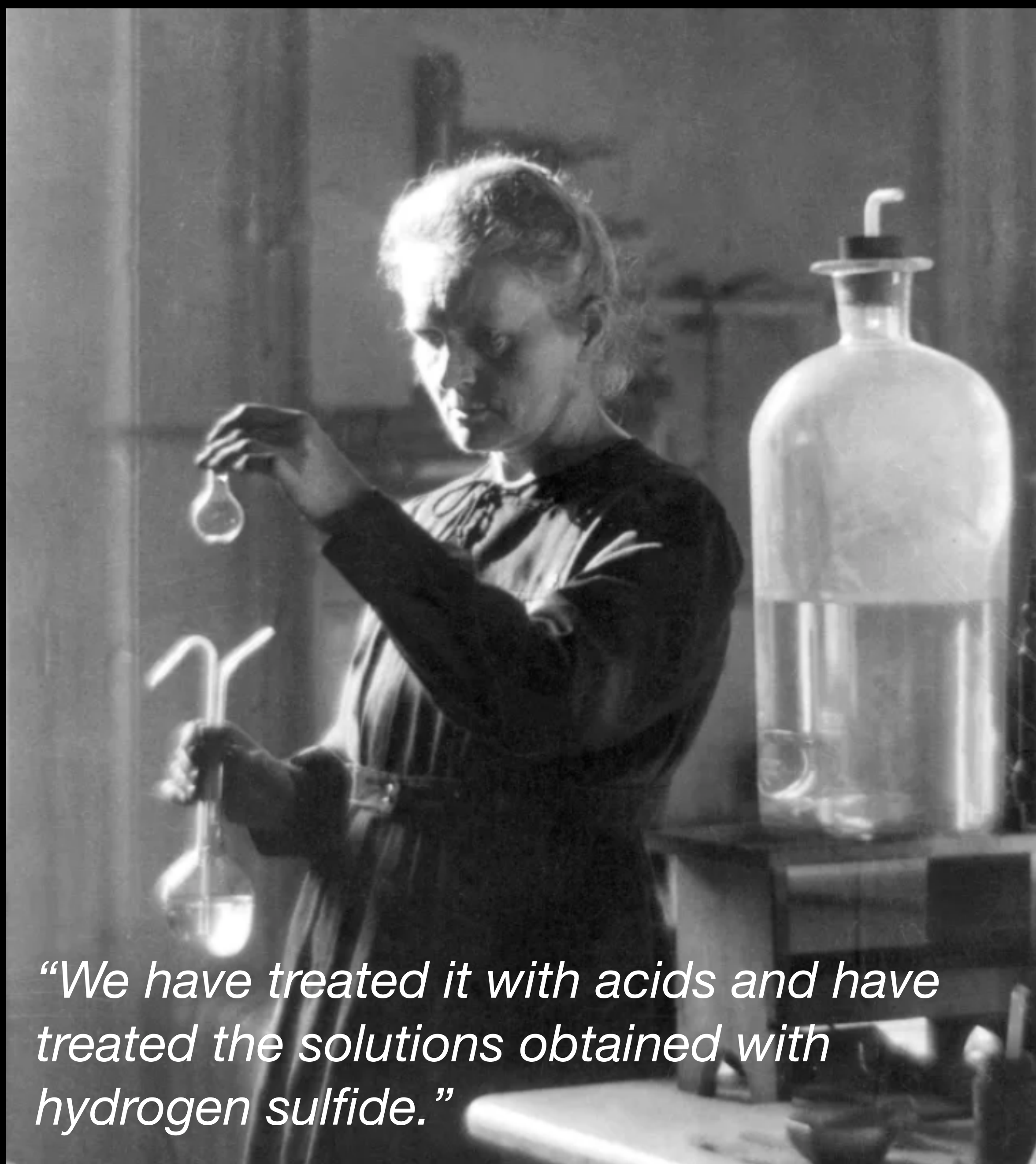

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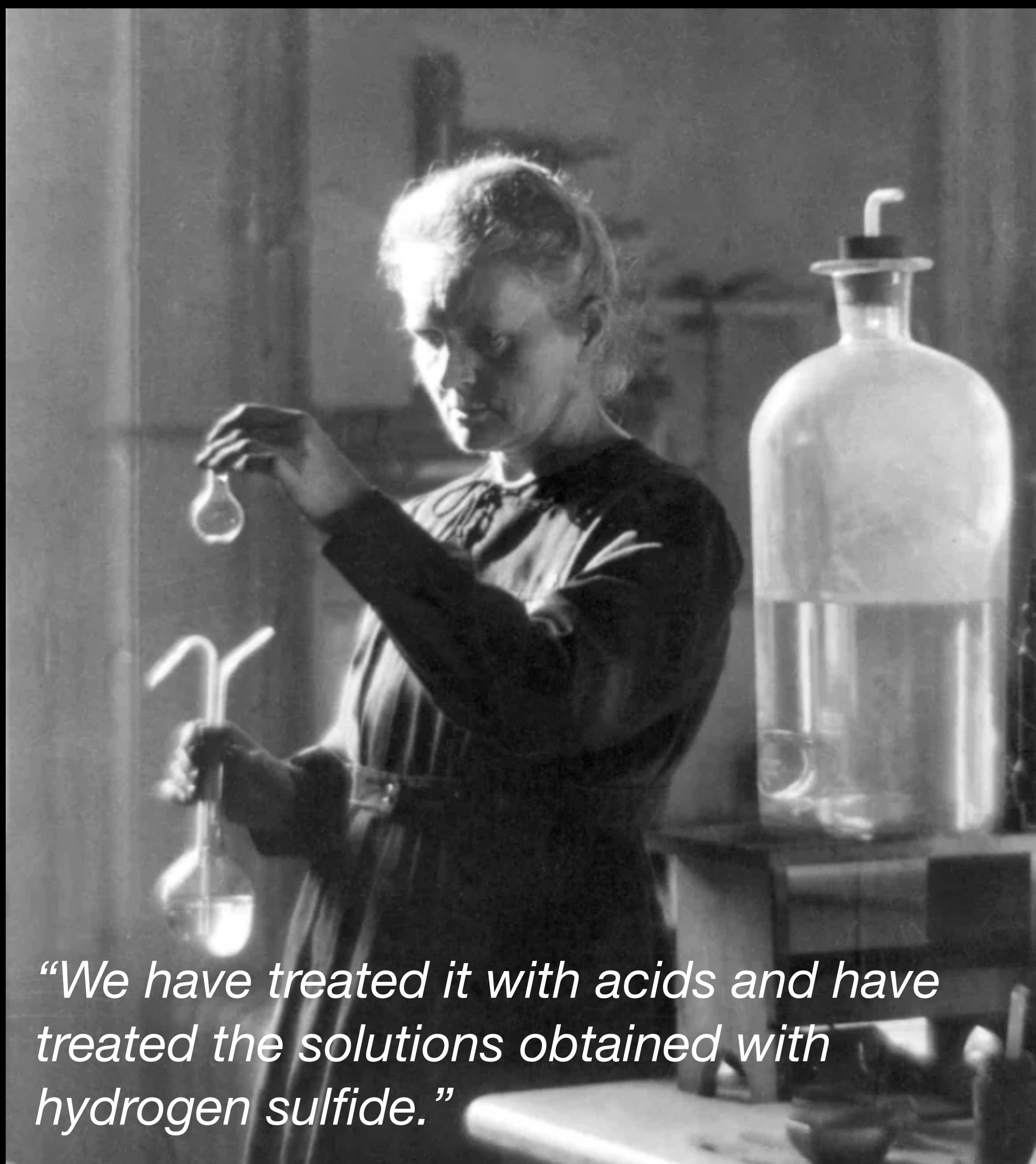

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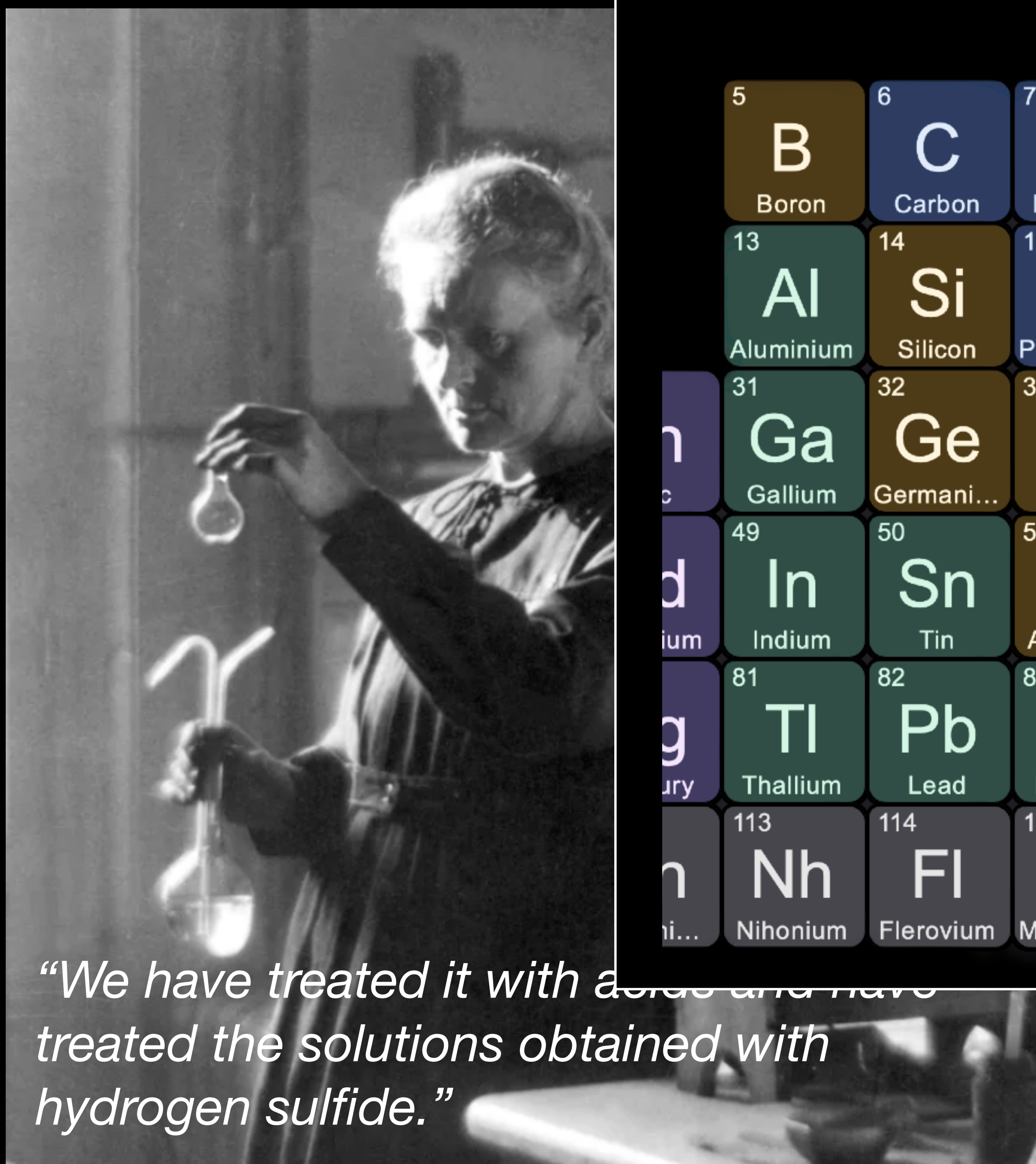

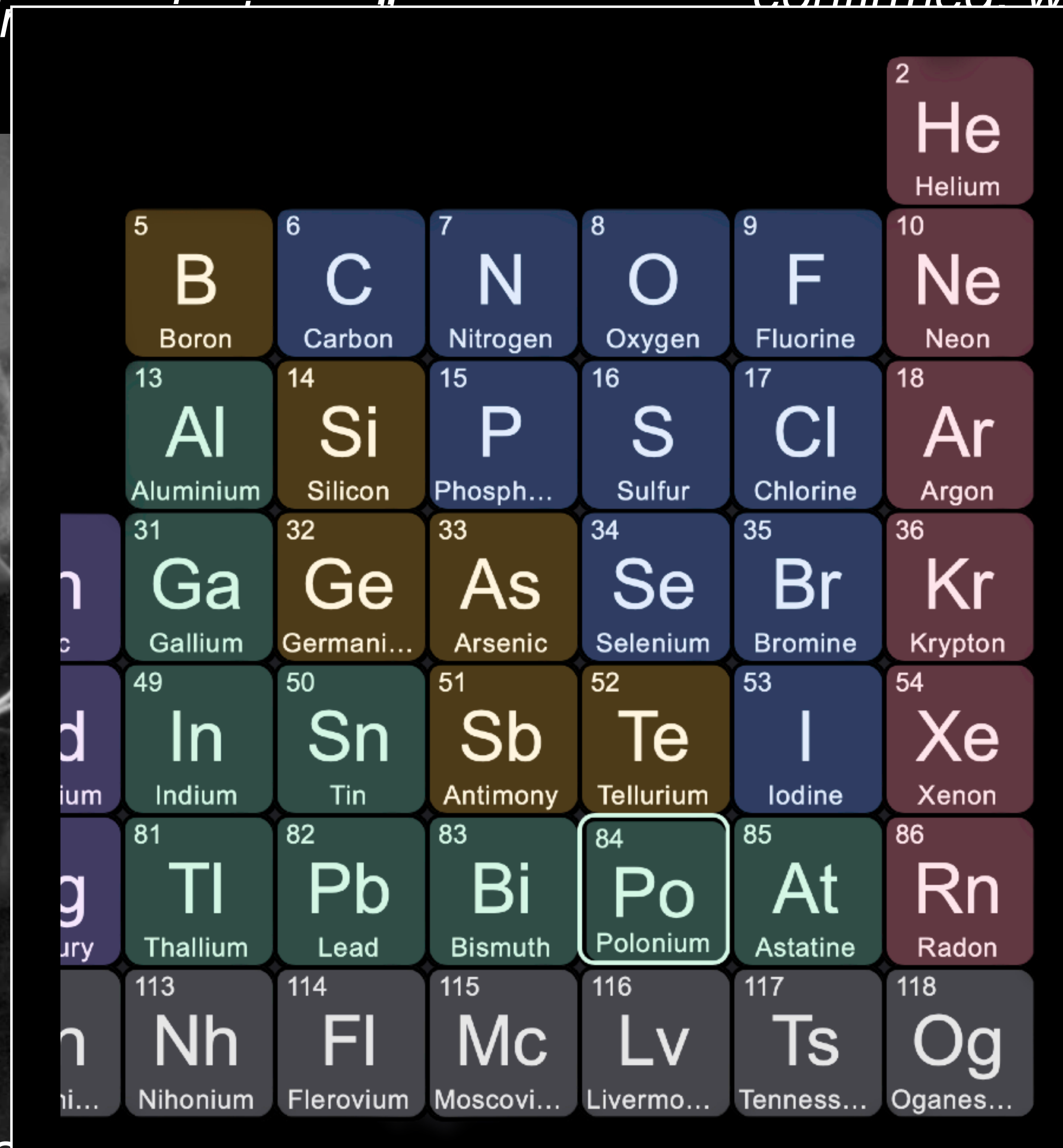

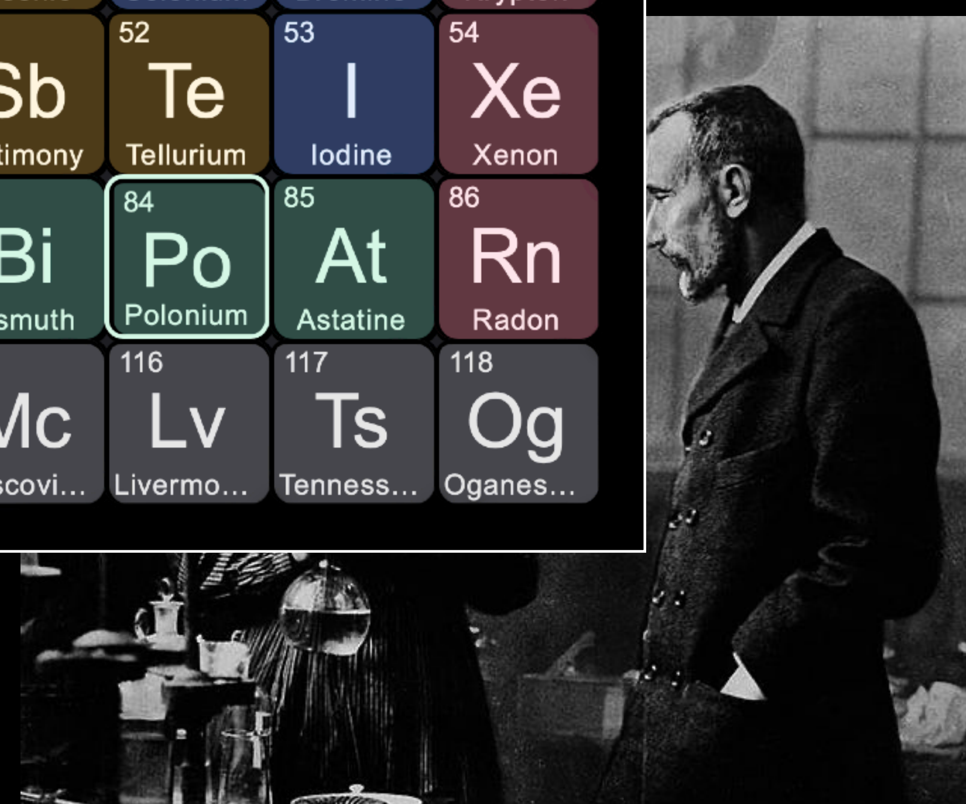

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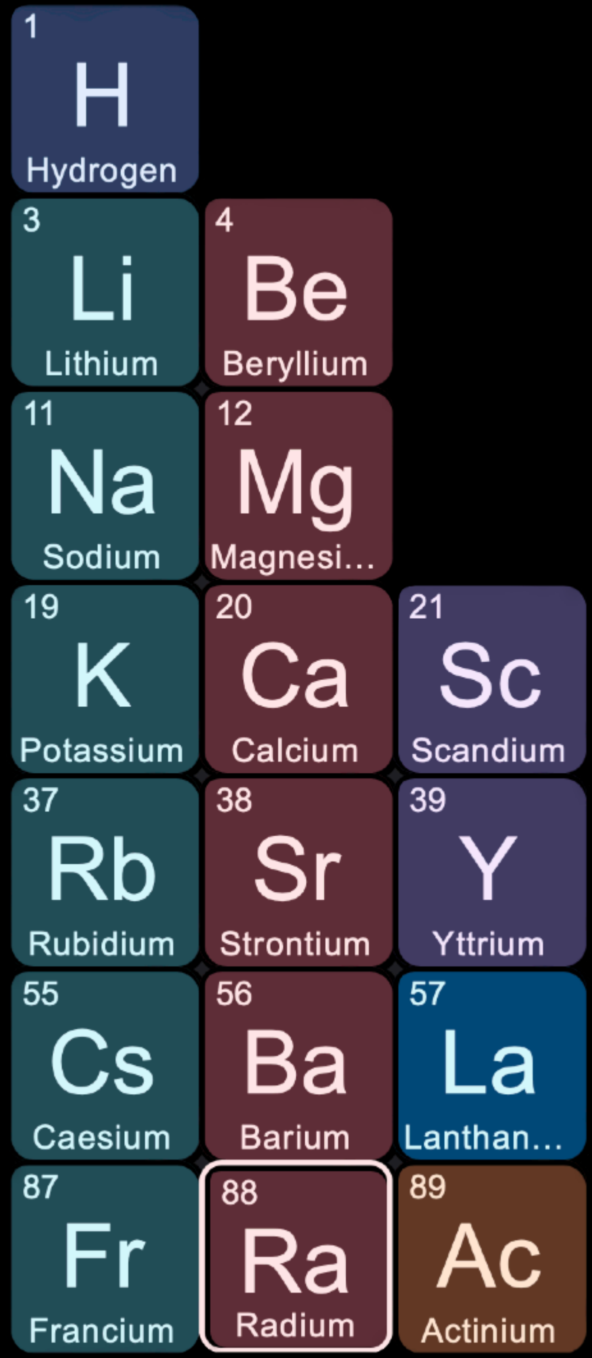

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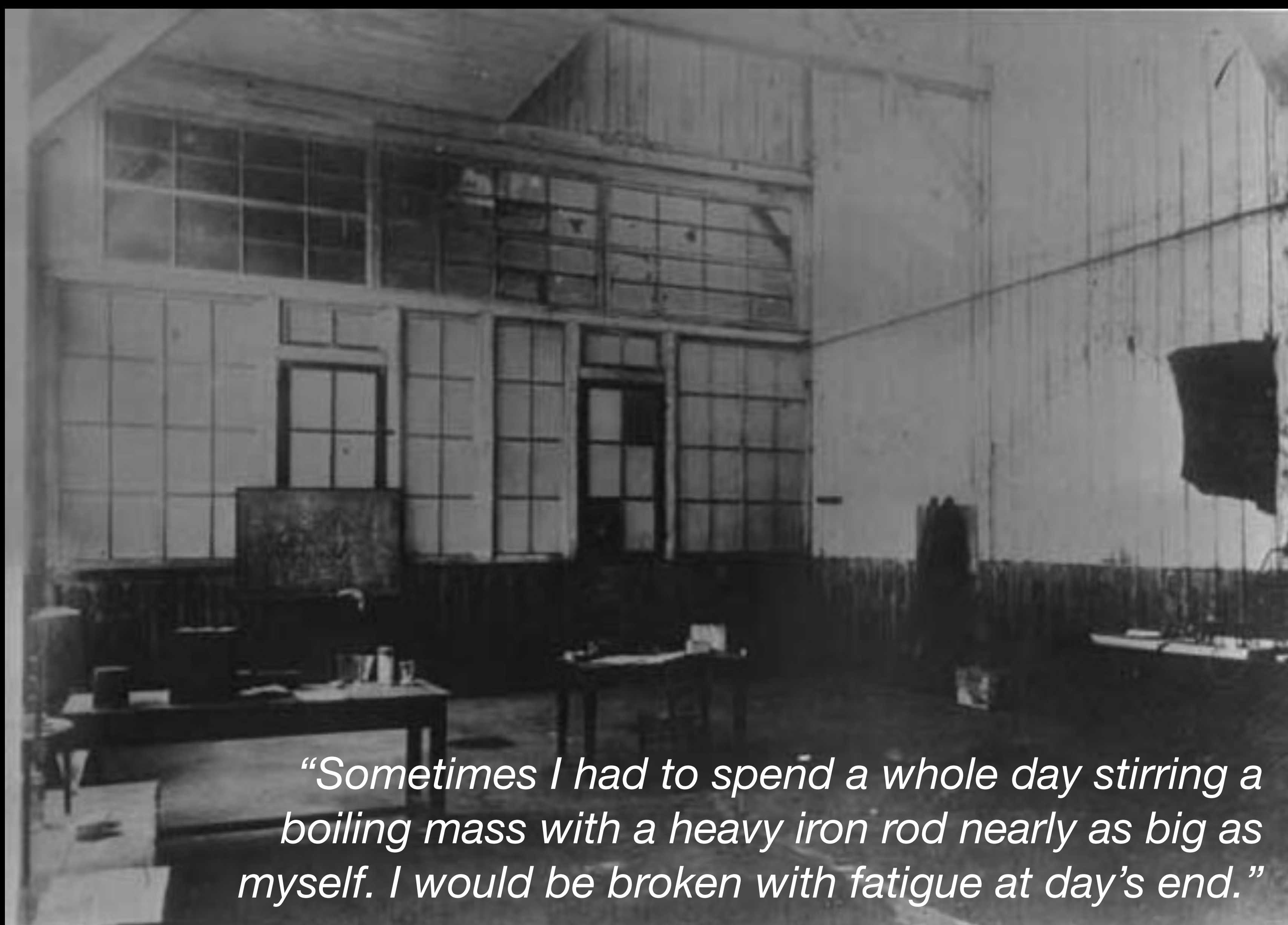

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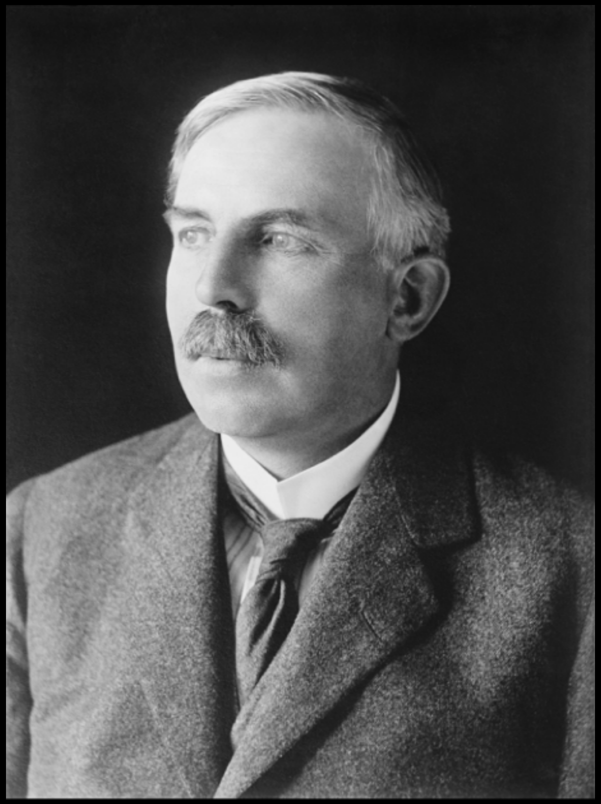

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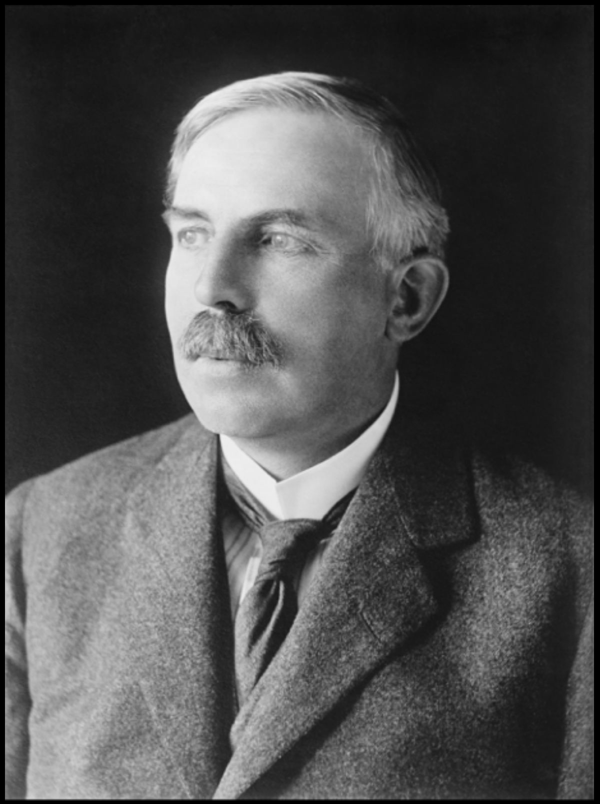
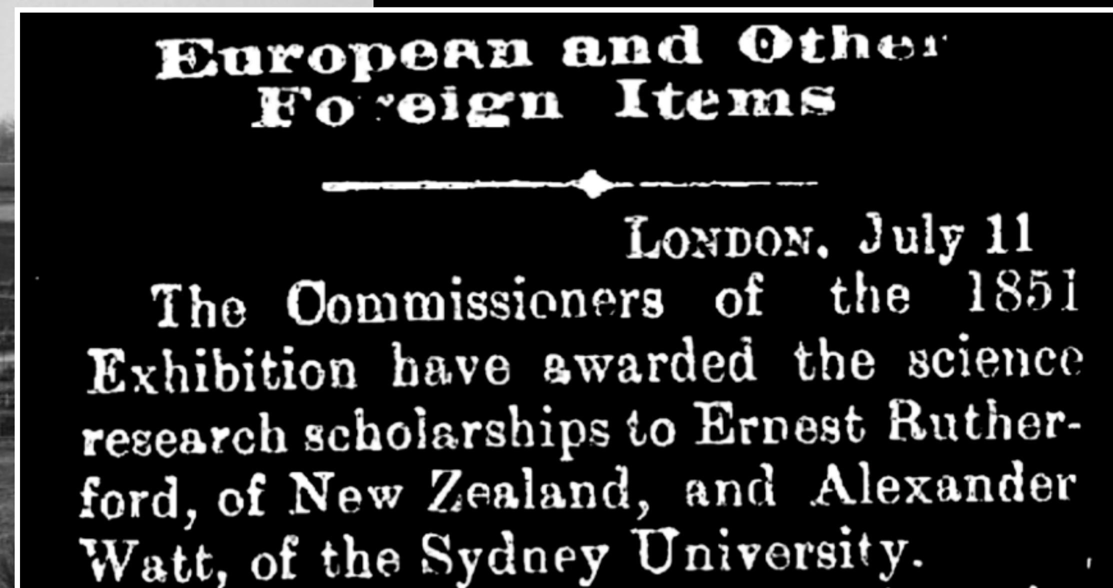


Ernest Rutherford

His ticket overseas



European and Other Foreign Items

London, July 11

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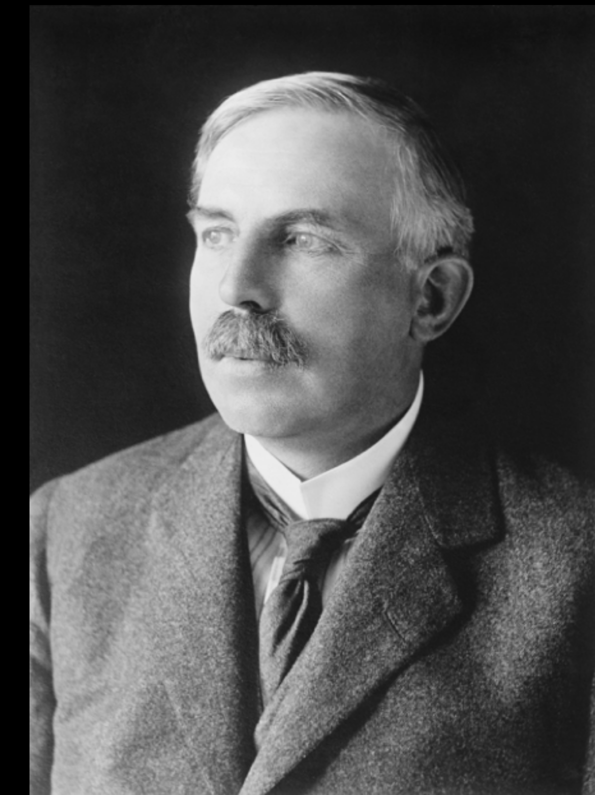

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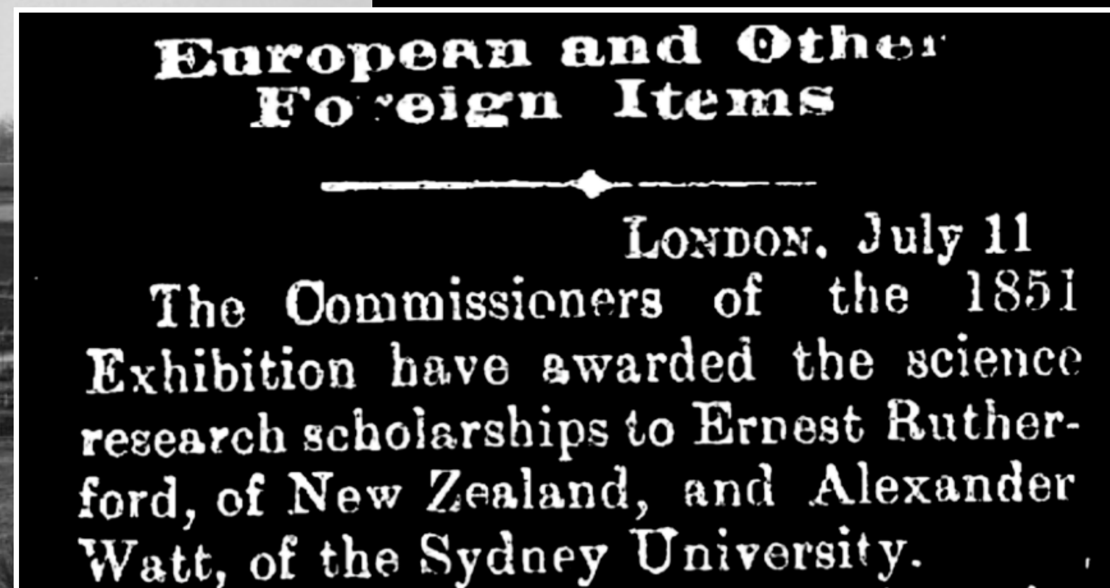

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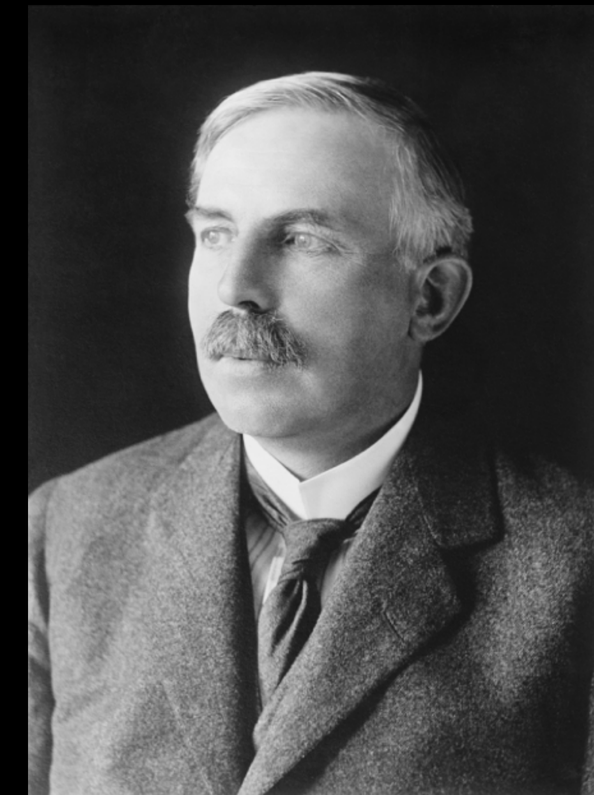
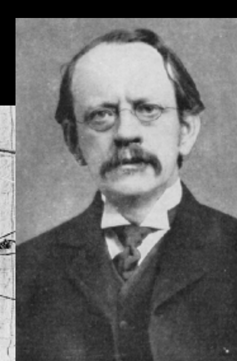
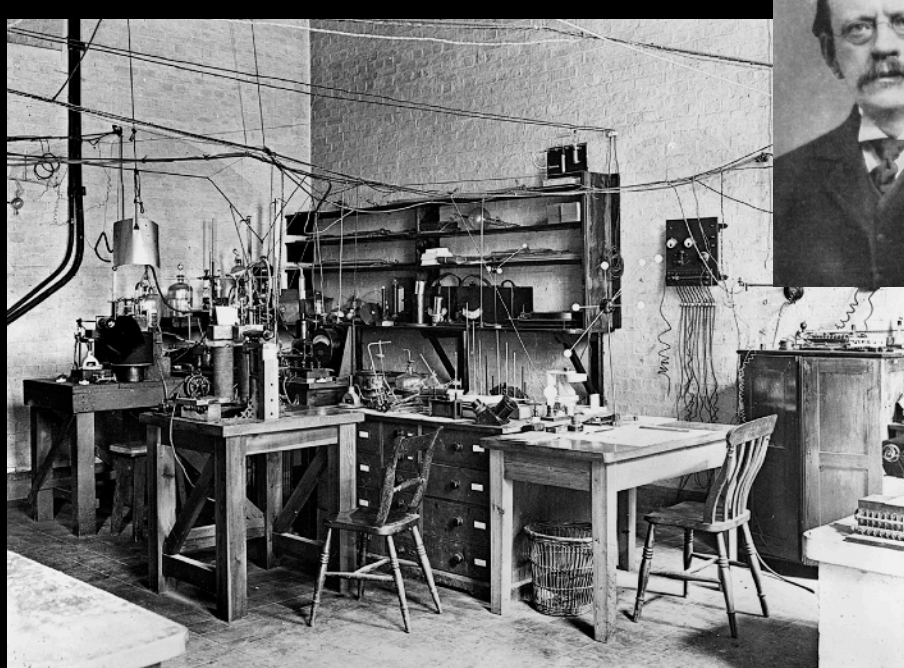


At the Cavendish with other "aliens"





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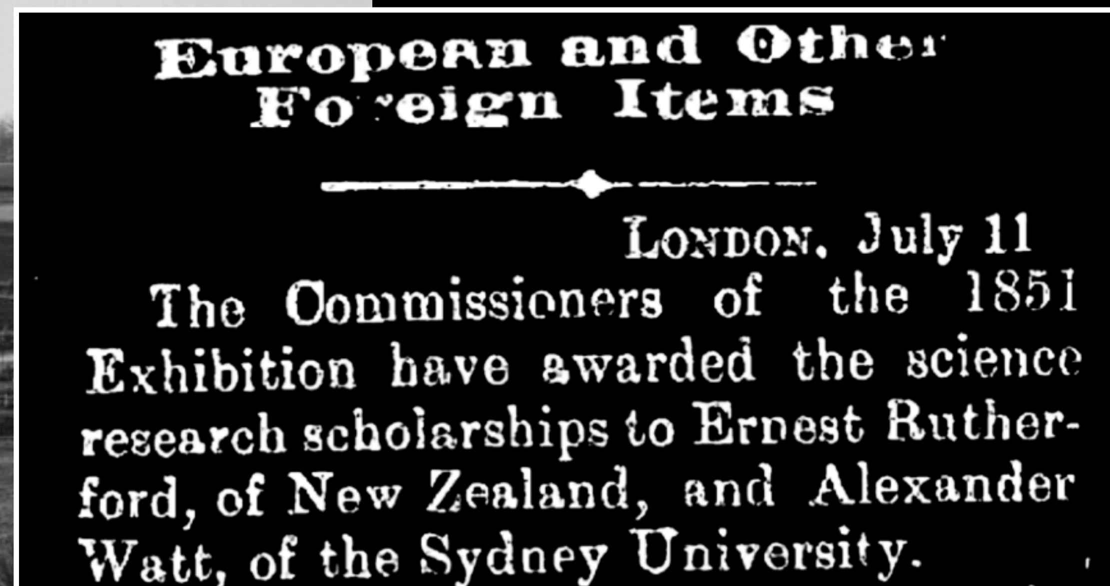

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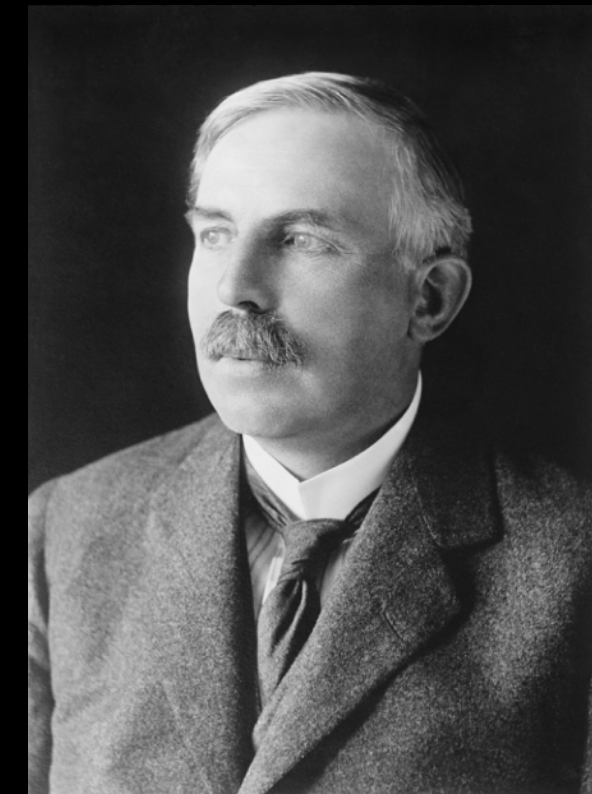

McGill University, Montreal

"Rejoice with me, my dear girl, for matrimony is looming in the distance."

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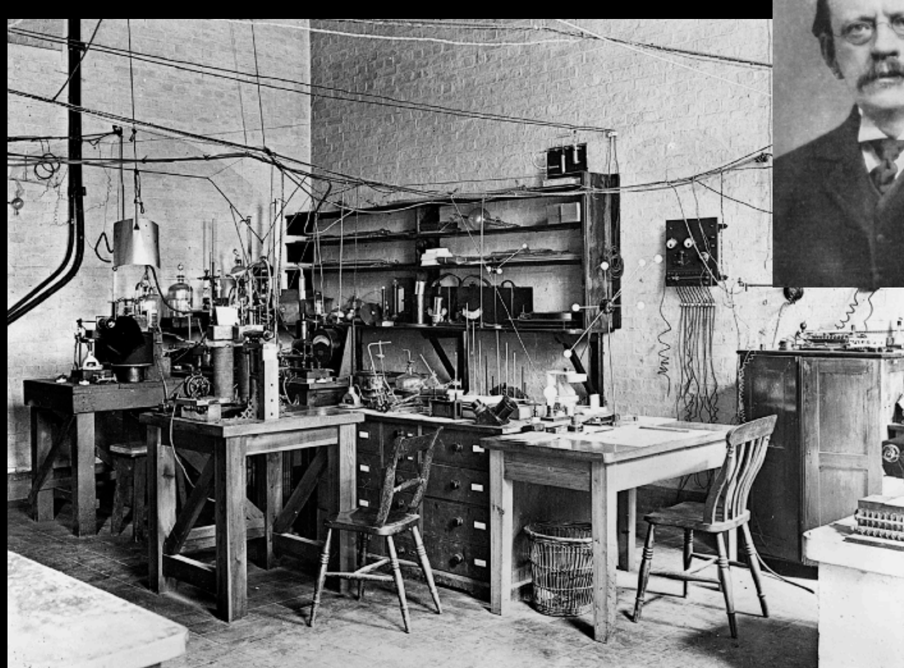
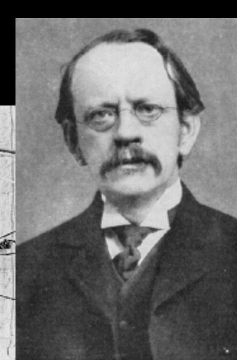
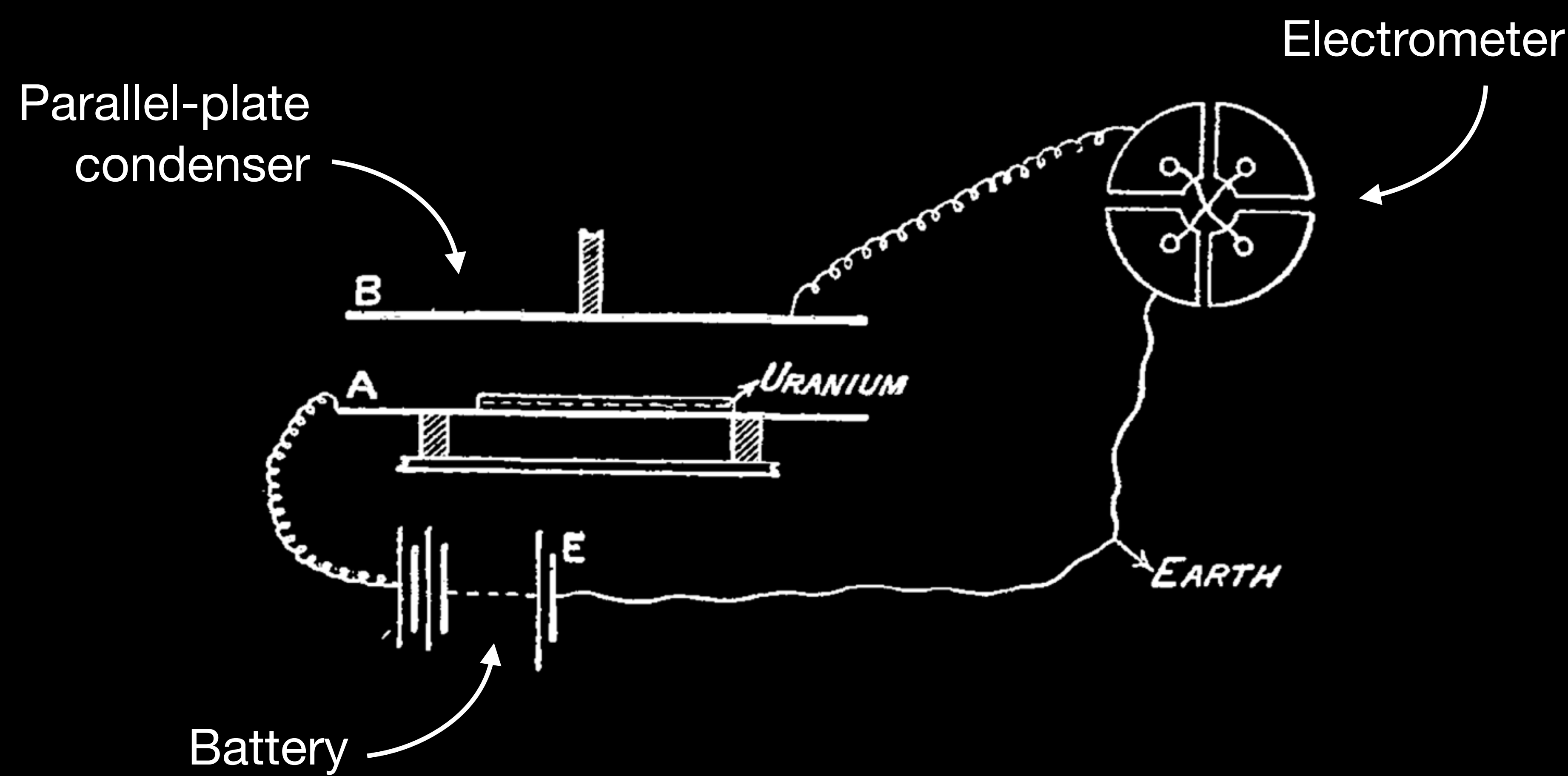




How penetrating are the rays?

Radiation measurement in the “Curie method”:



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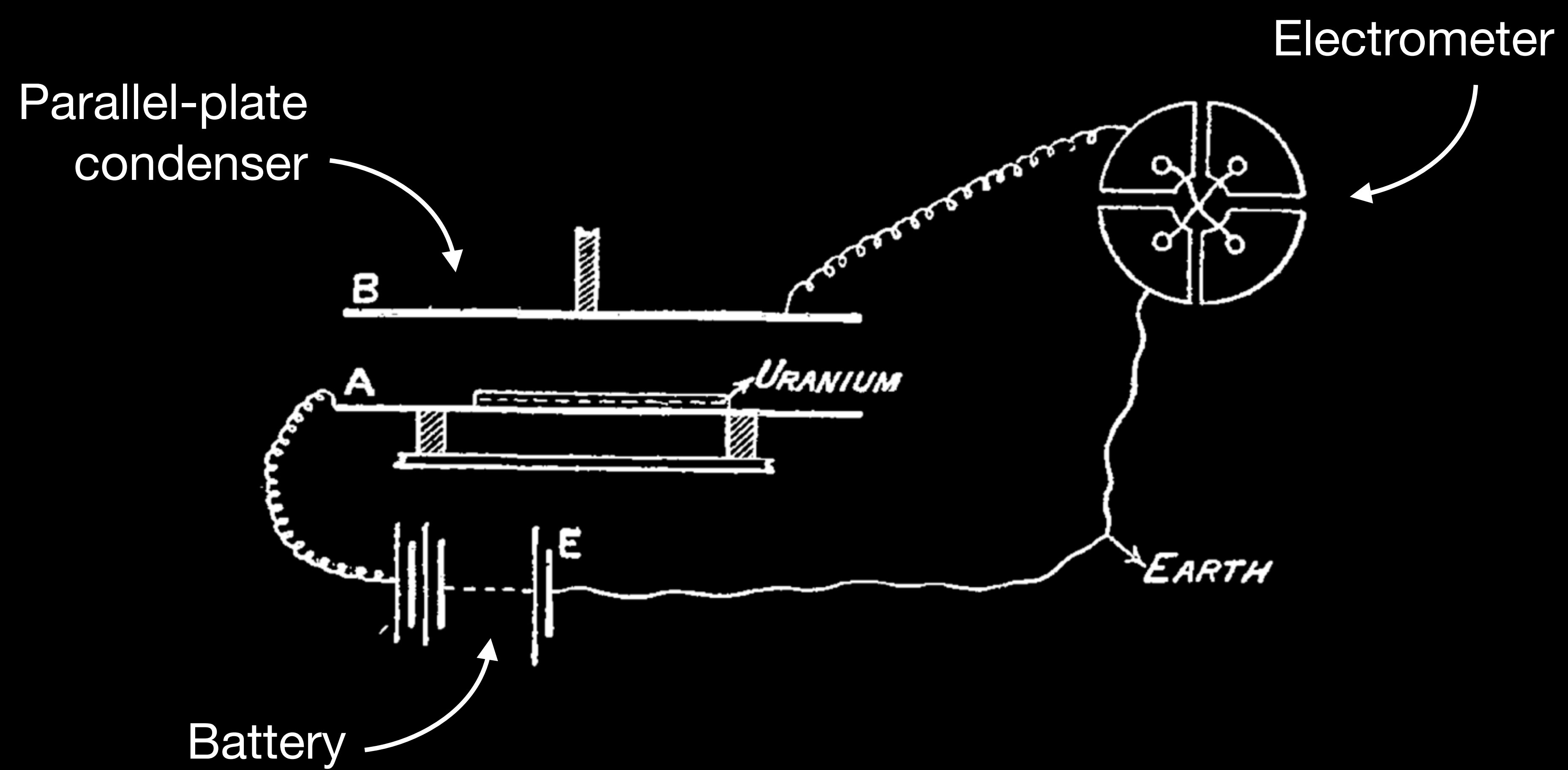

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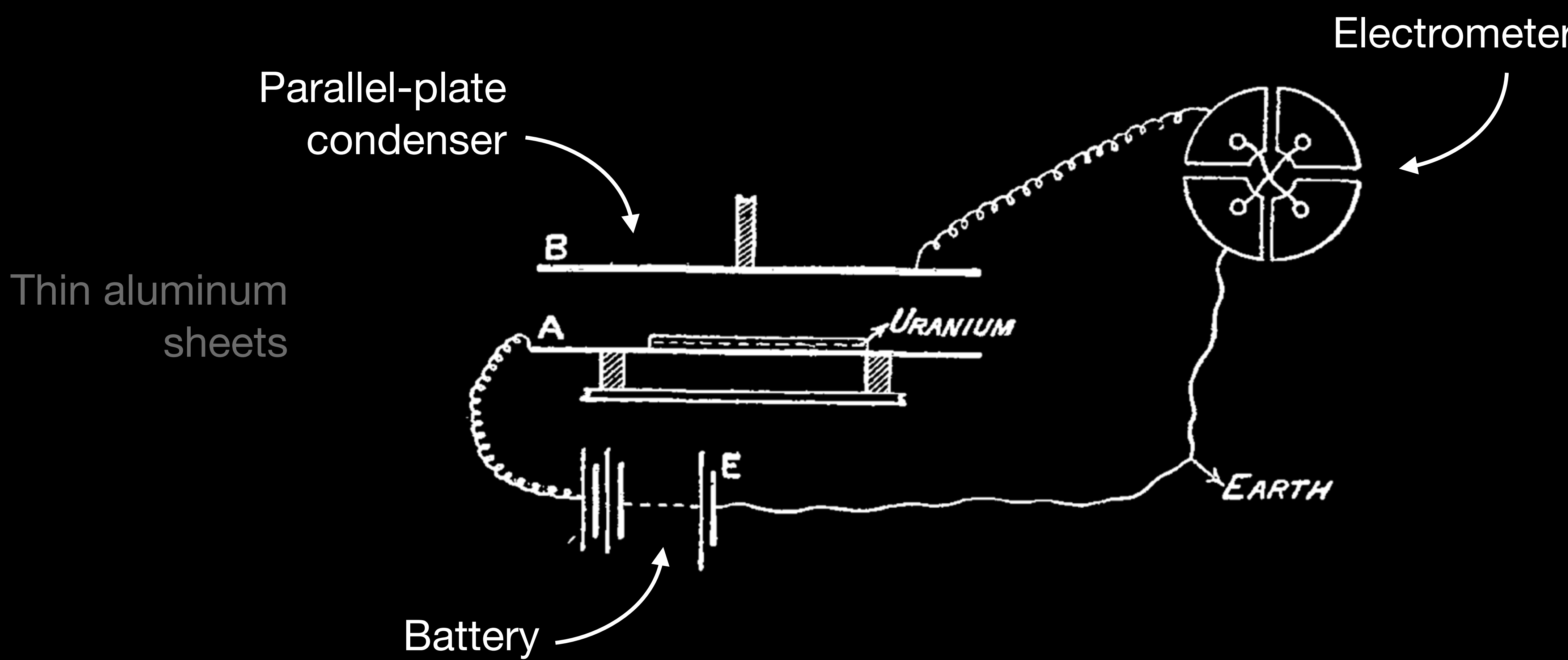

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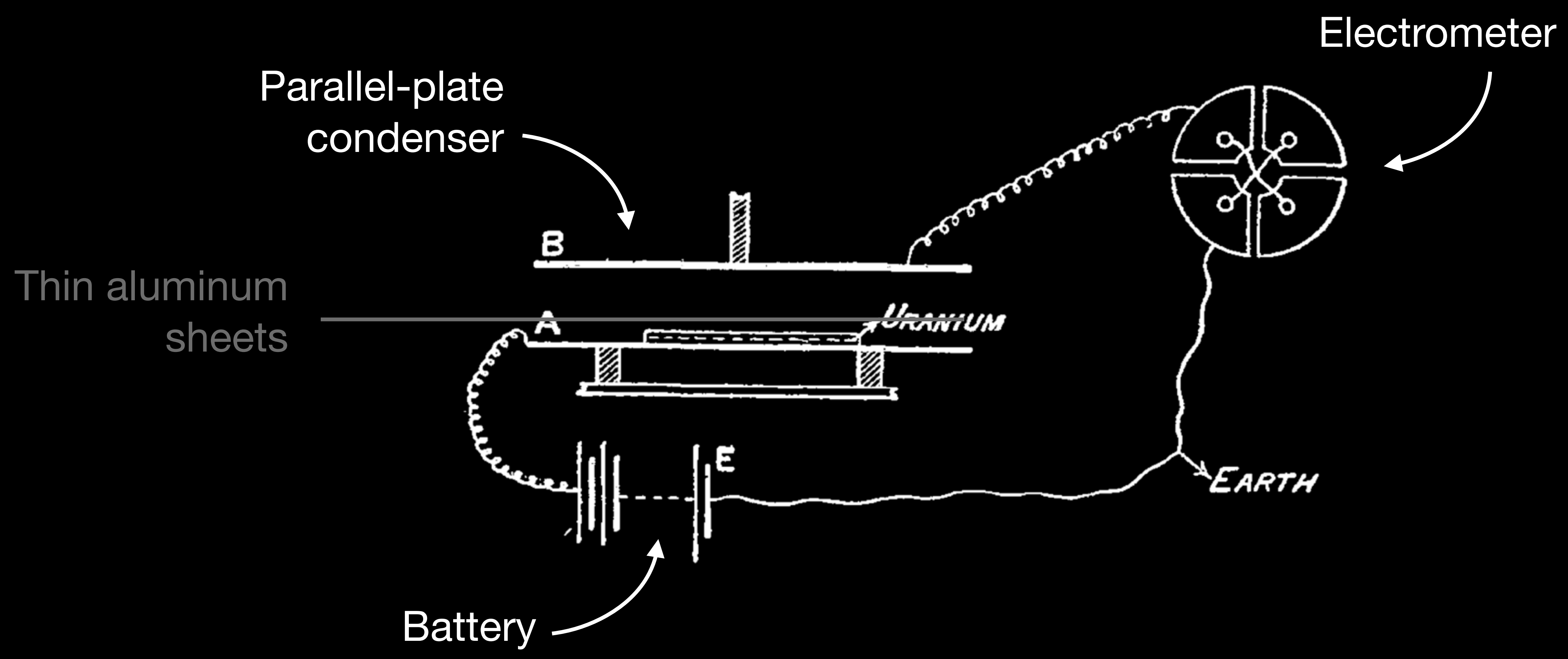

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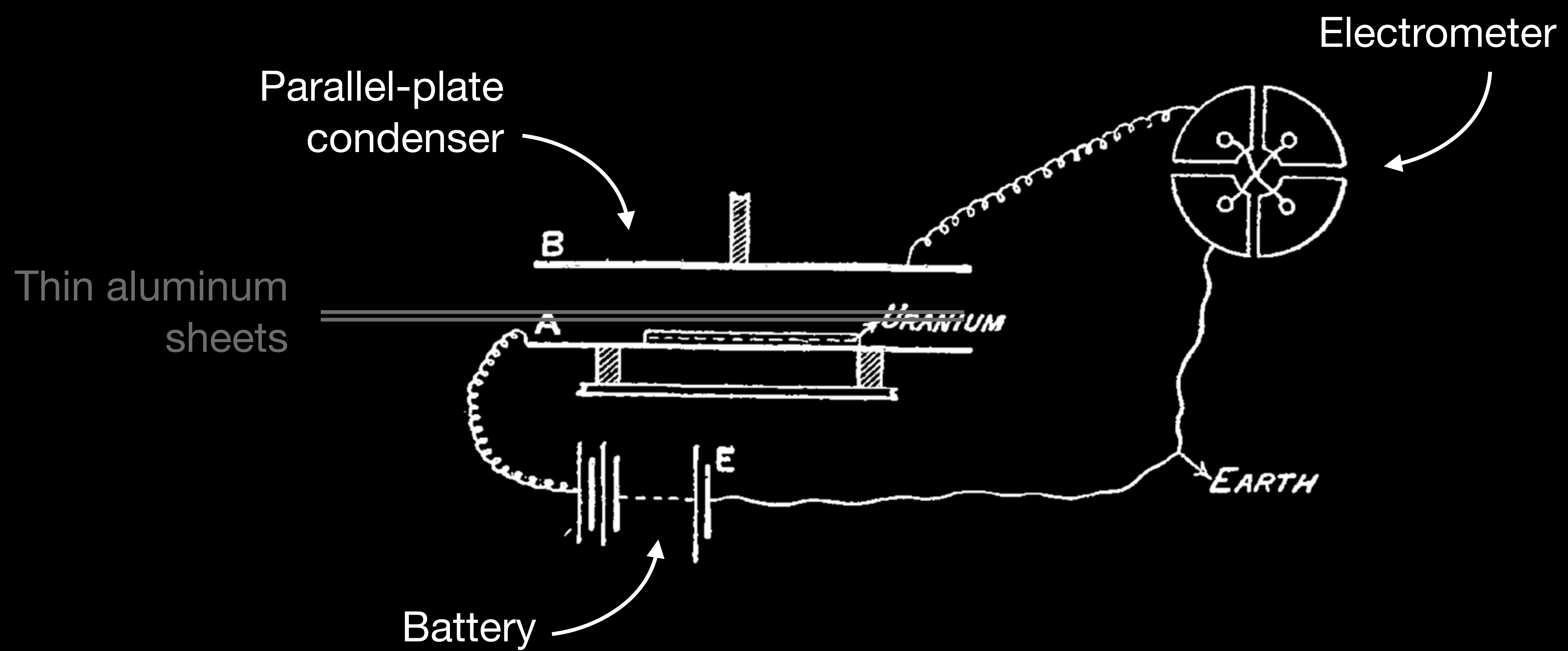

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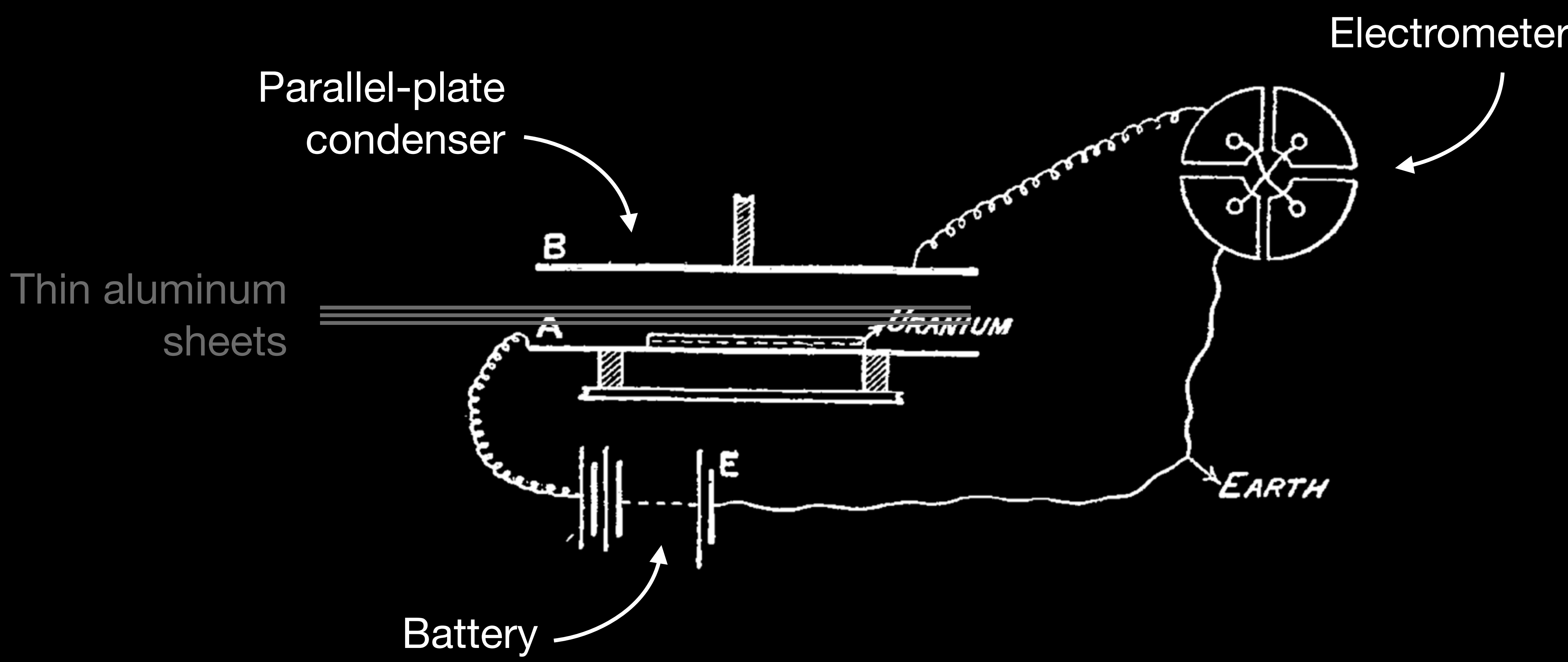

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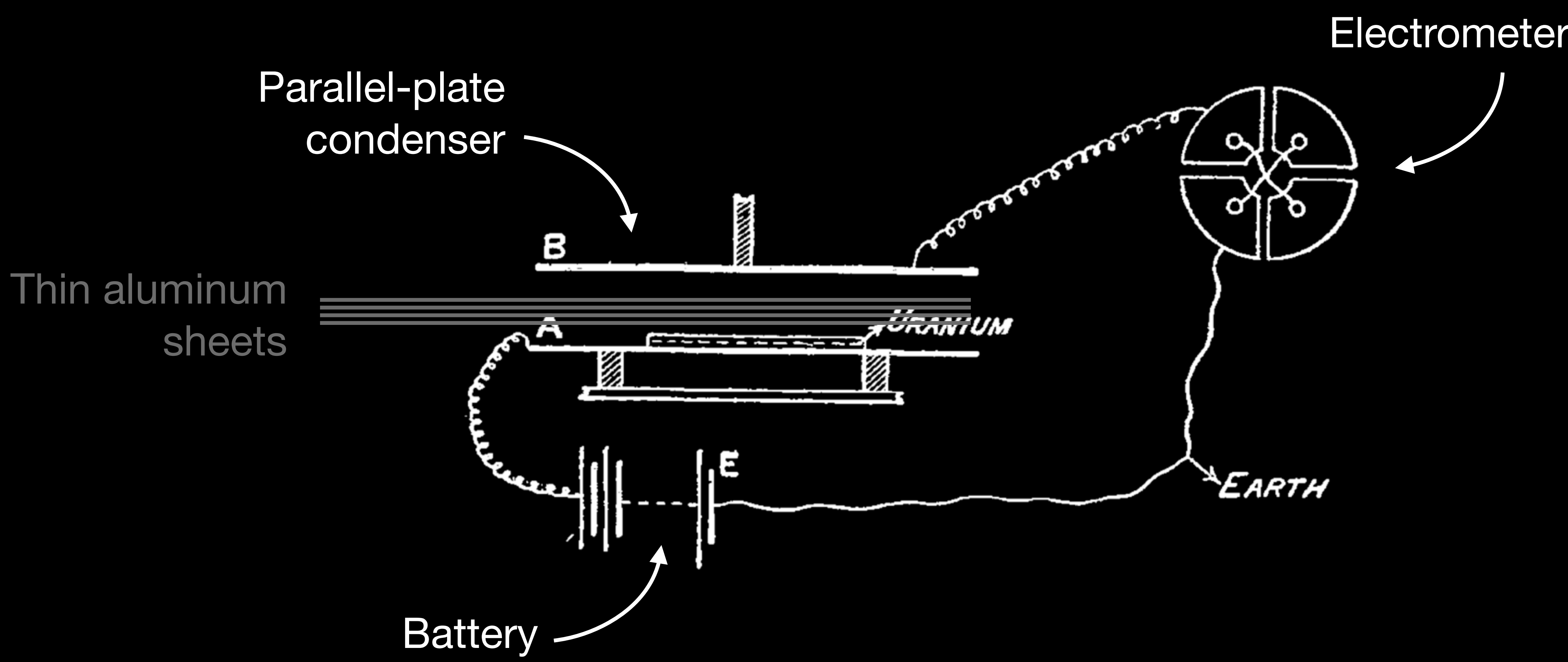

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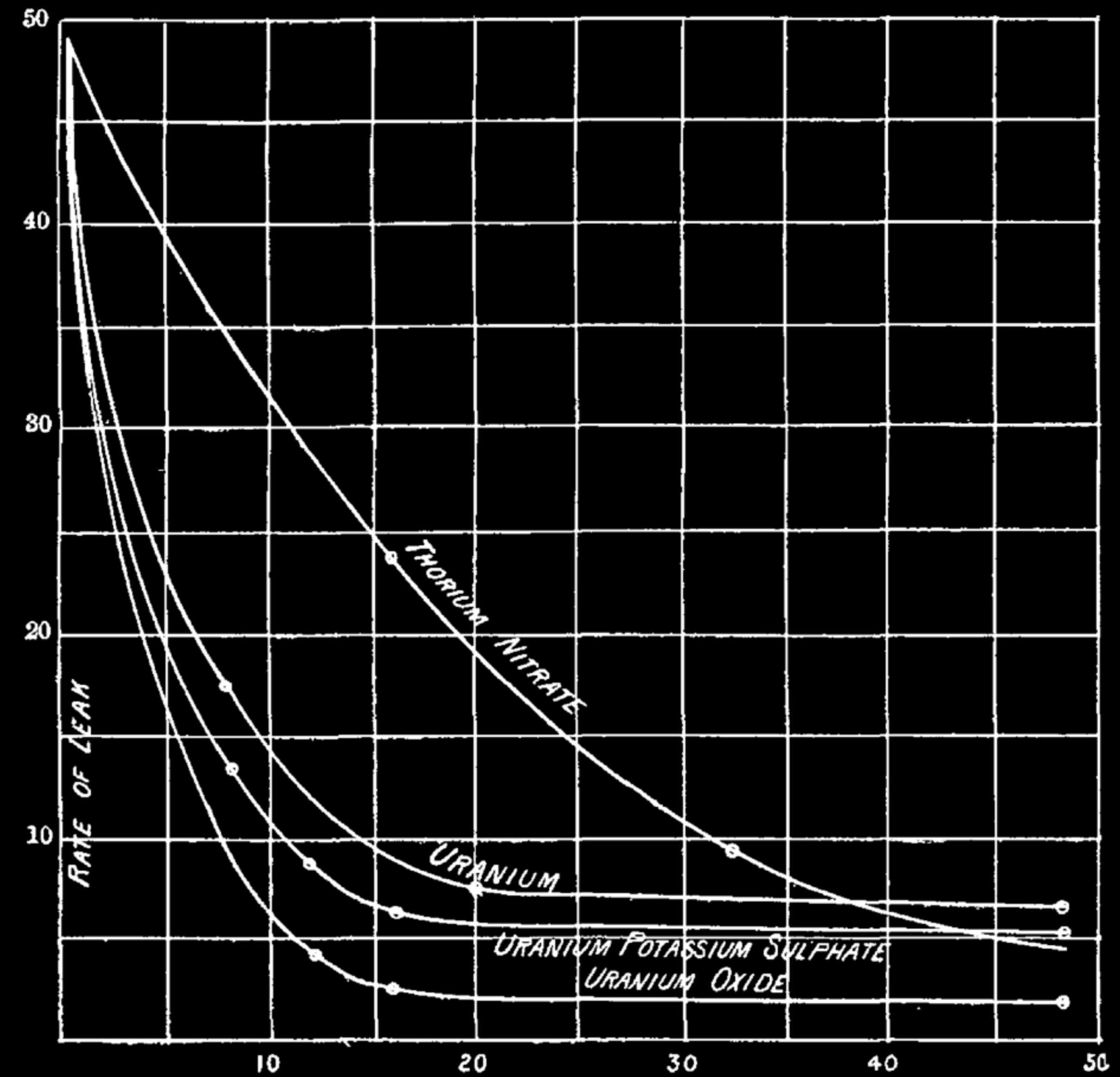
Intensity of radiation



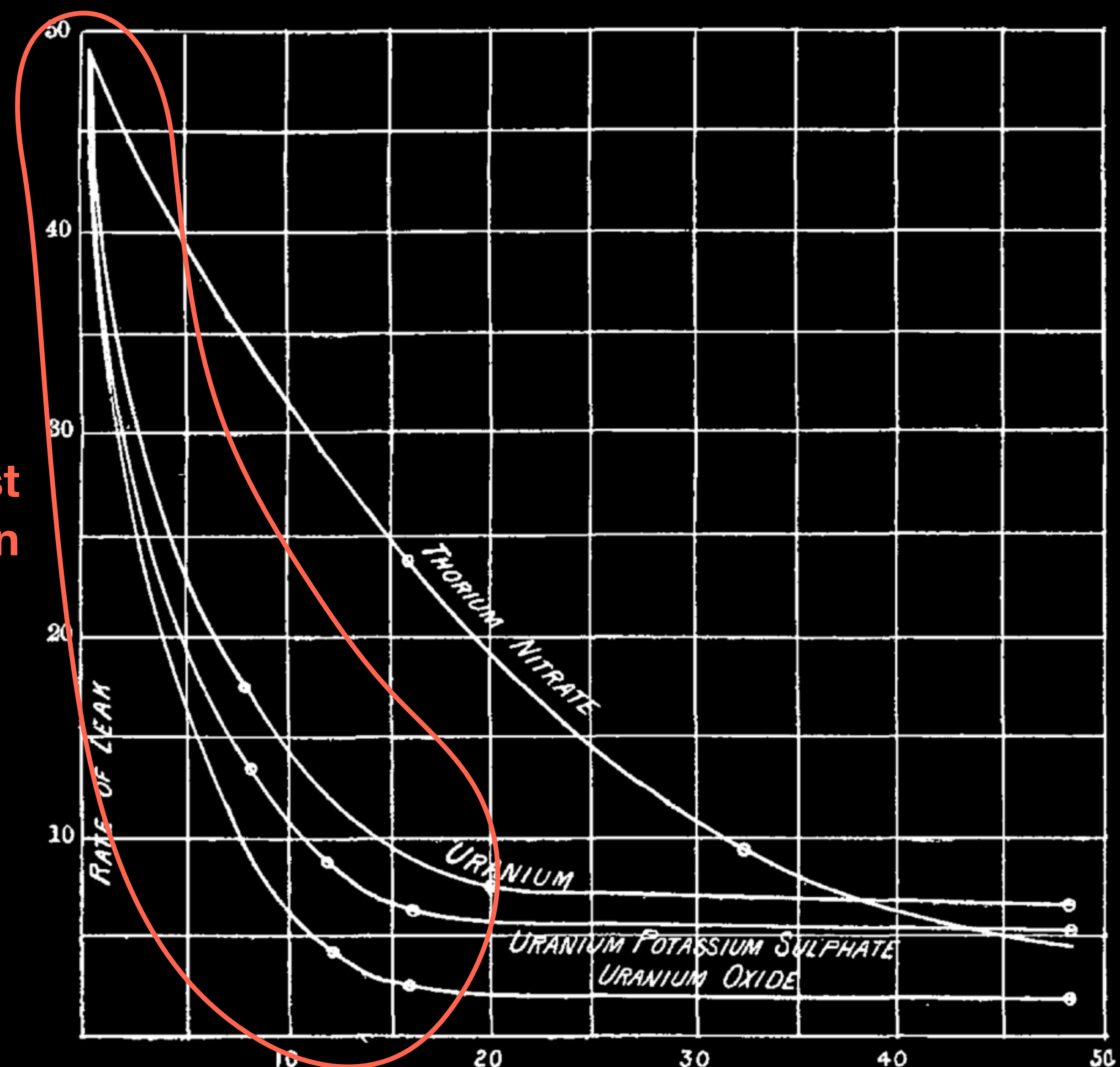
Number of aluminum sheets

"The aluminium foil in this case was about 0.0005 cm thick."

Only one kind of rays?

Intensity of radiation

Very fast reduction



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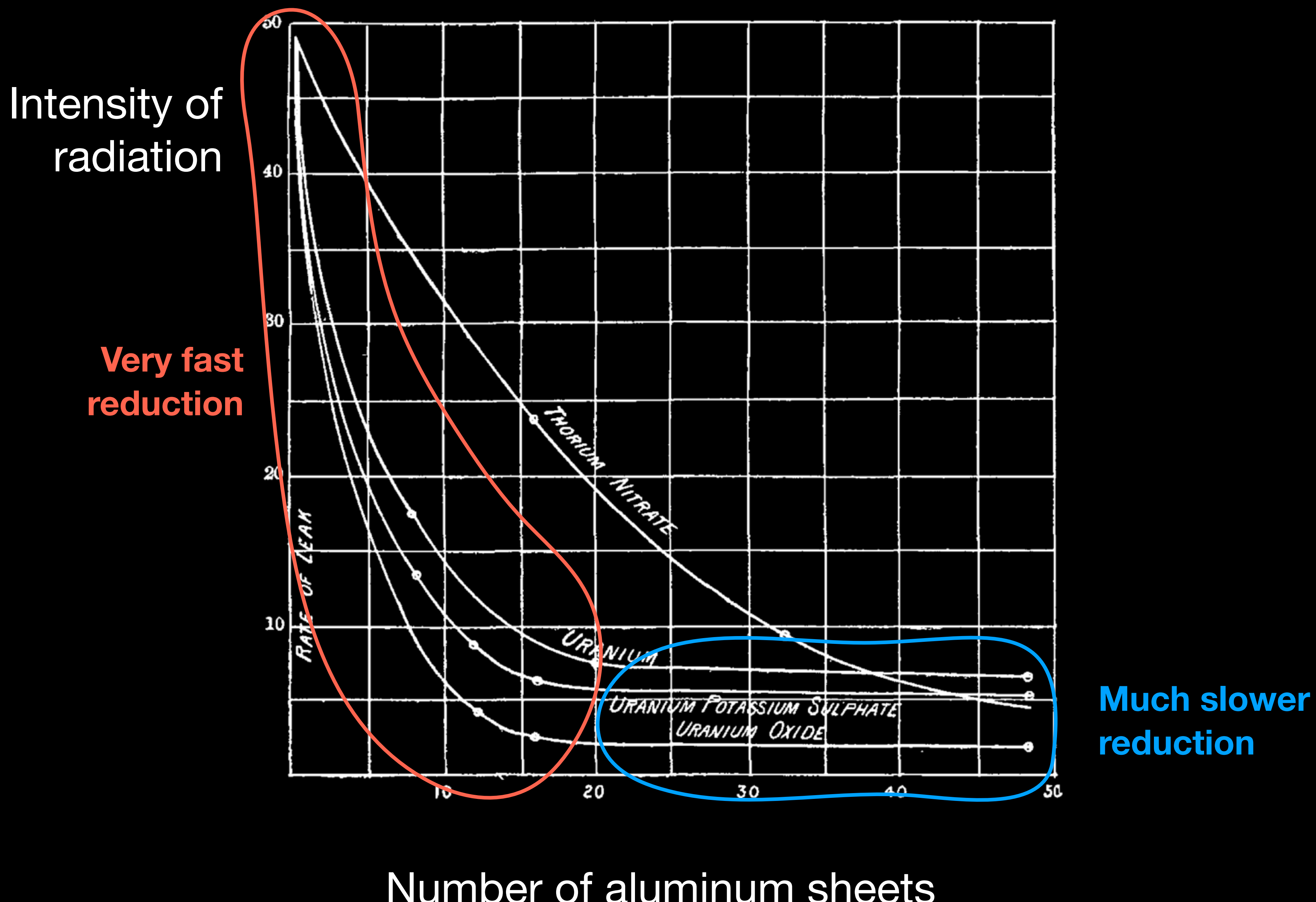

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More than one kind of rays!

"These experiments show that the uranium radiation is complex and that there are present at least two distinct types of radiation."

More than one kind of rays!

Thin aluminum
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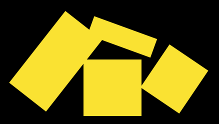

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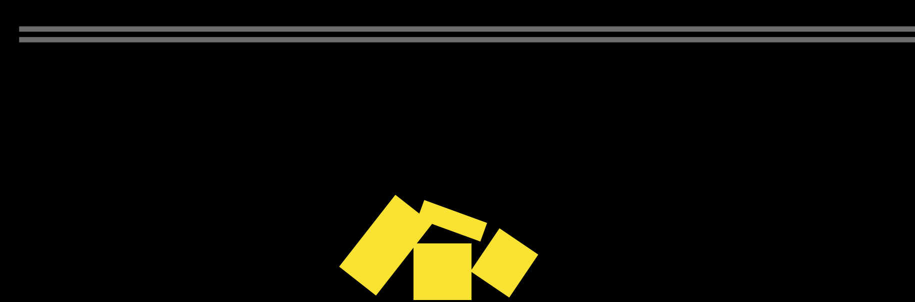

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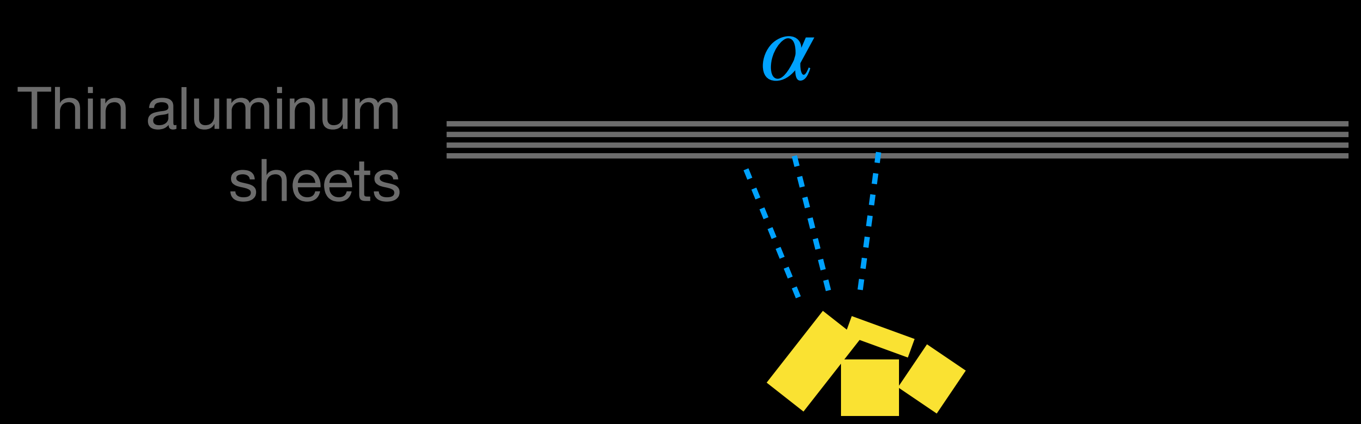

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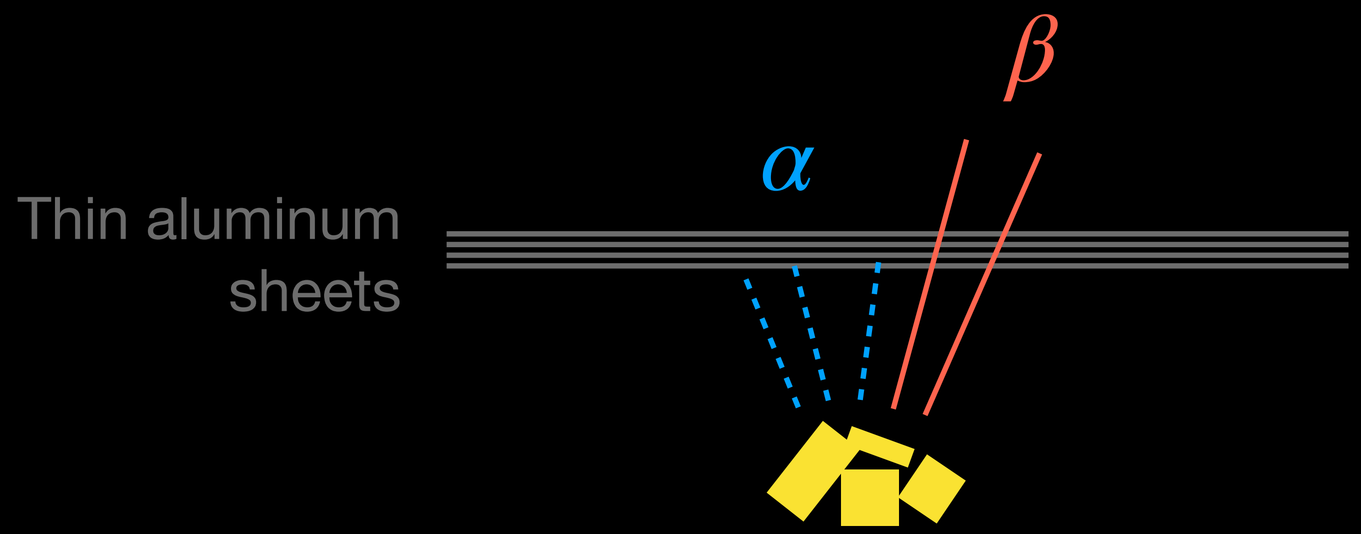

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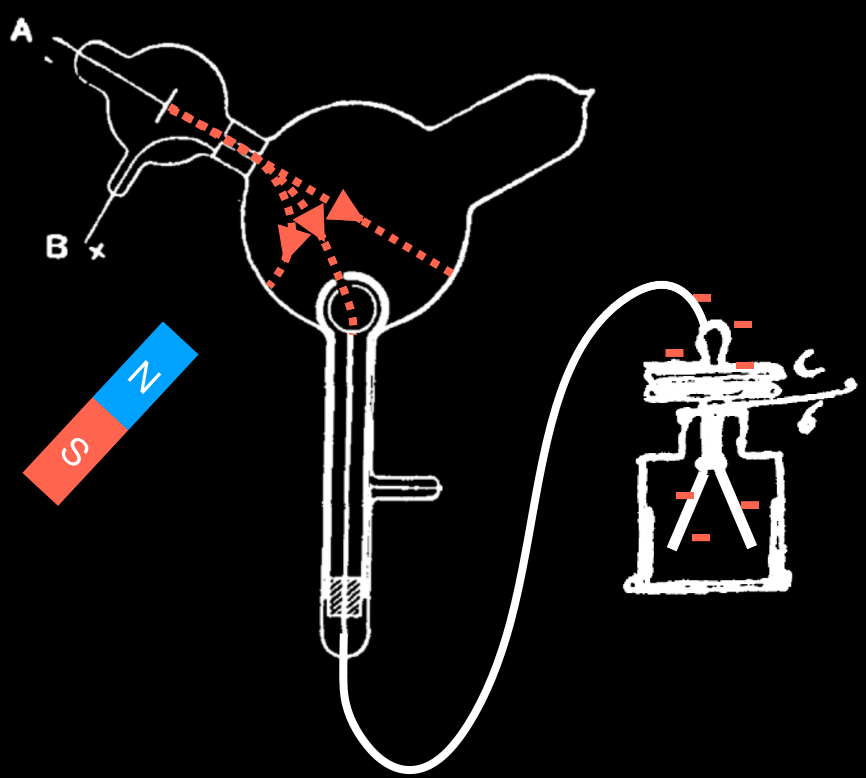

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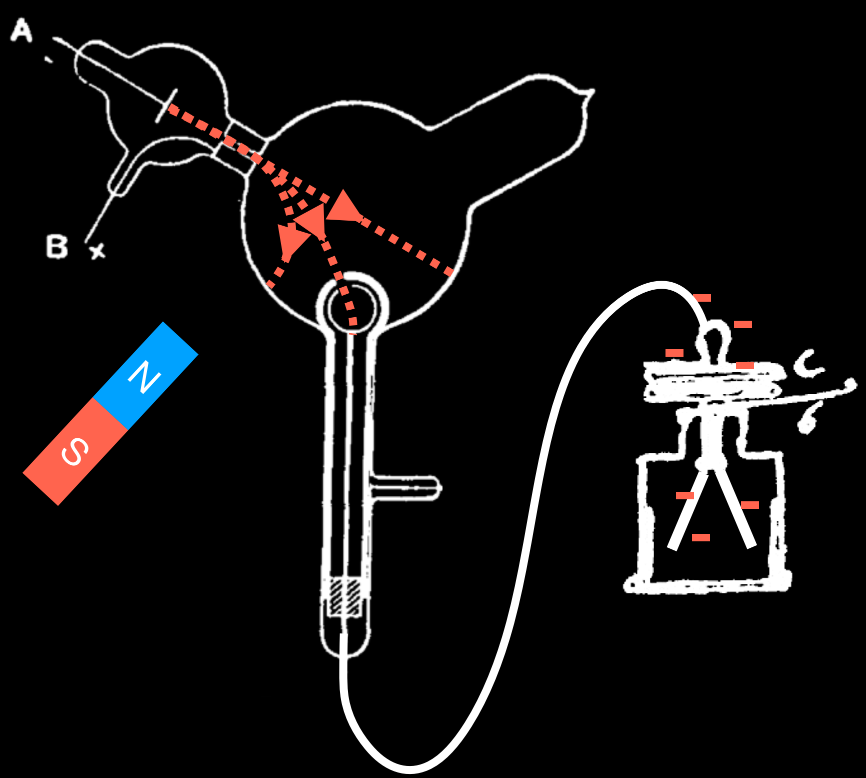

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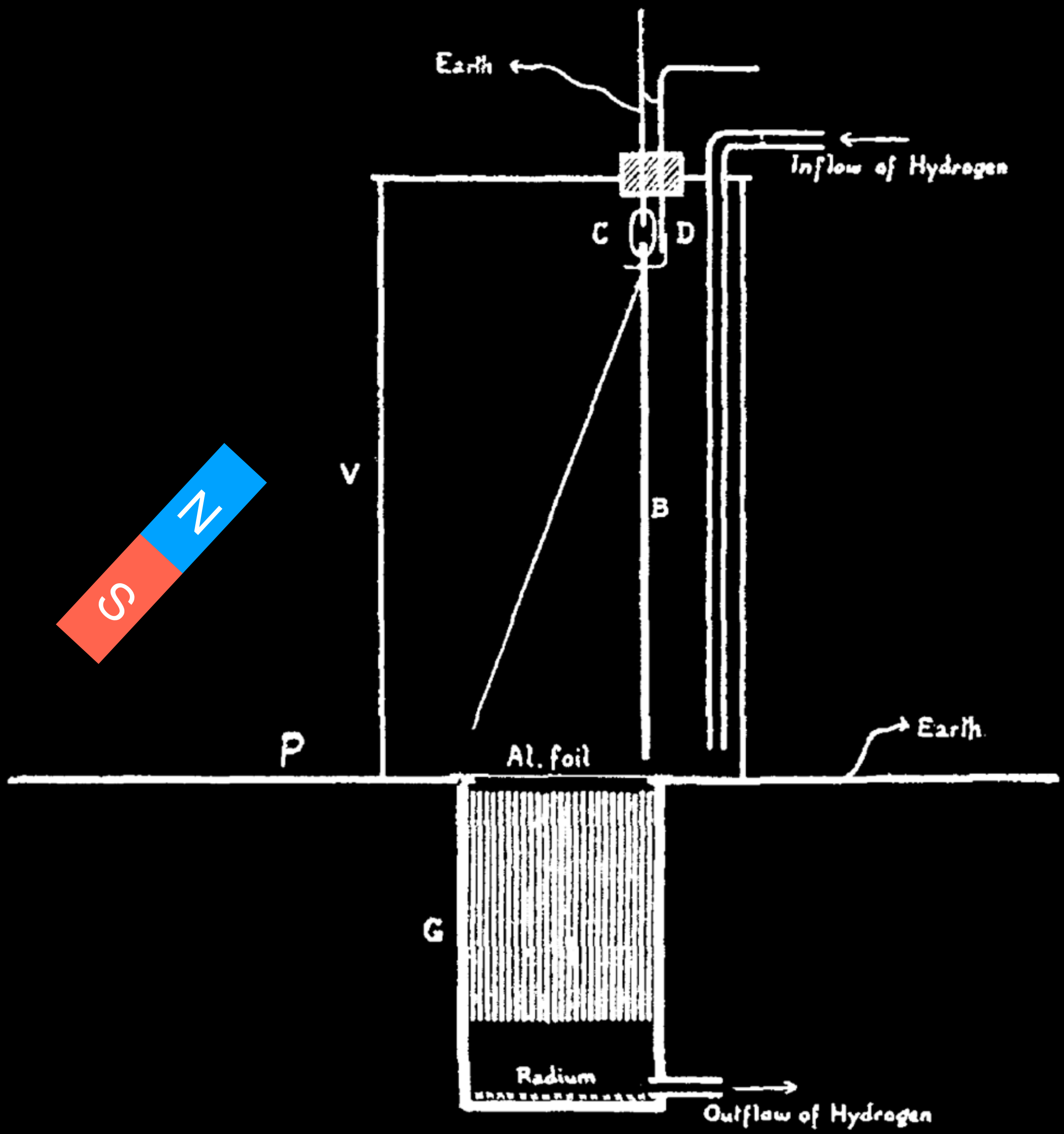

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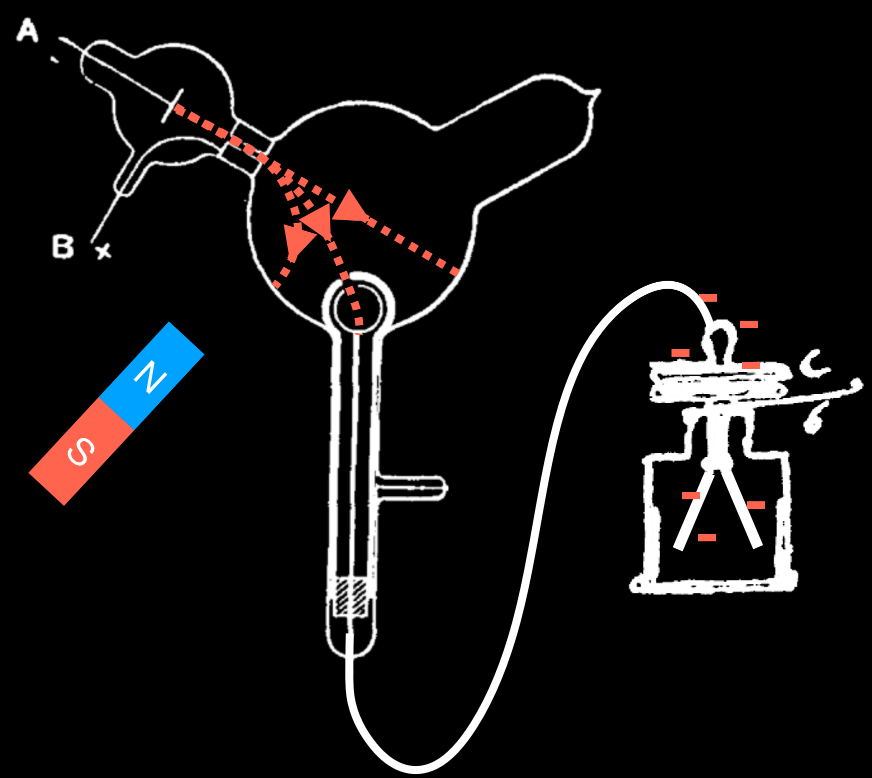

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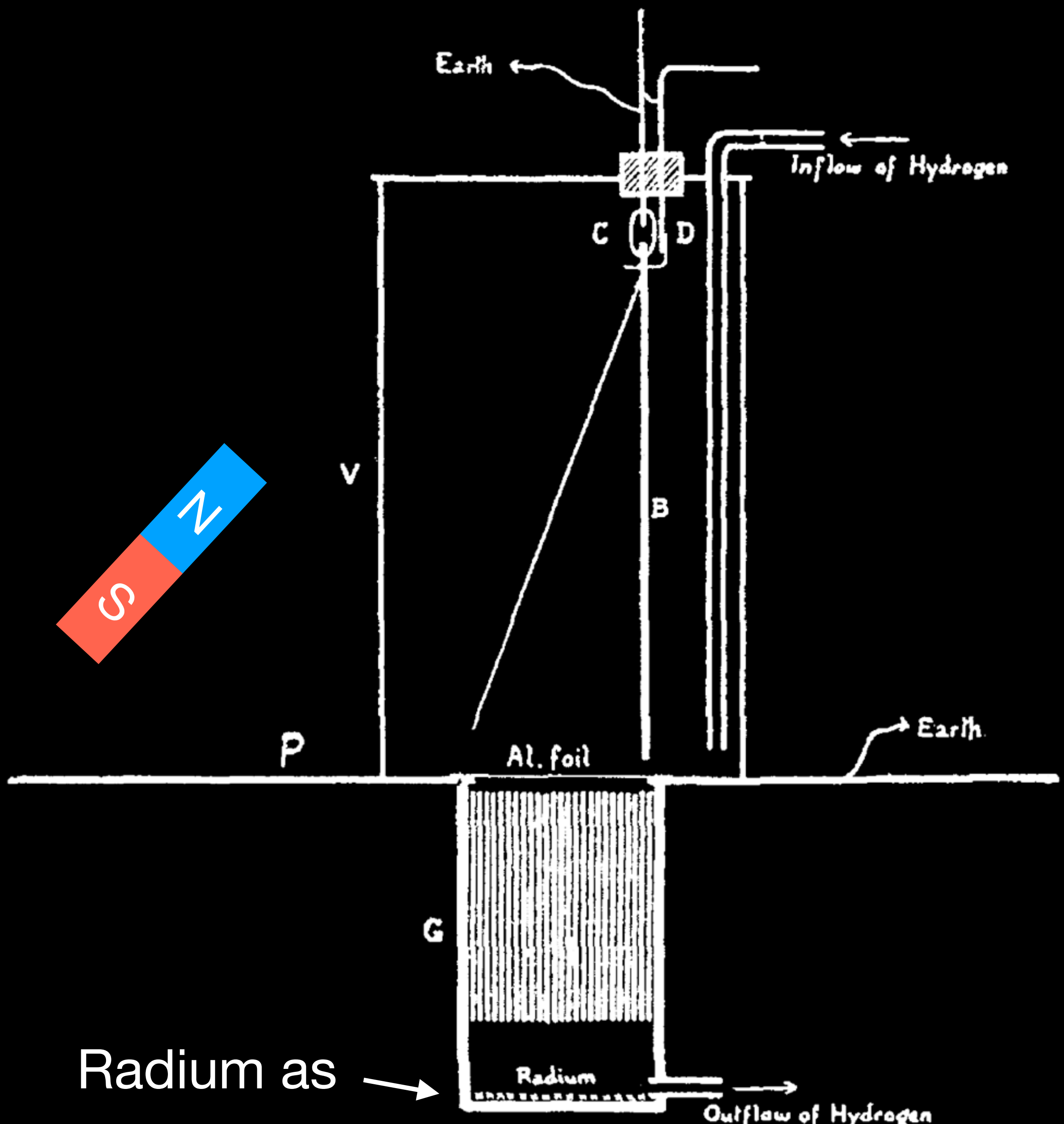

Radium as
α-radiation source

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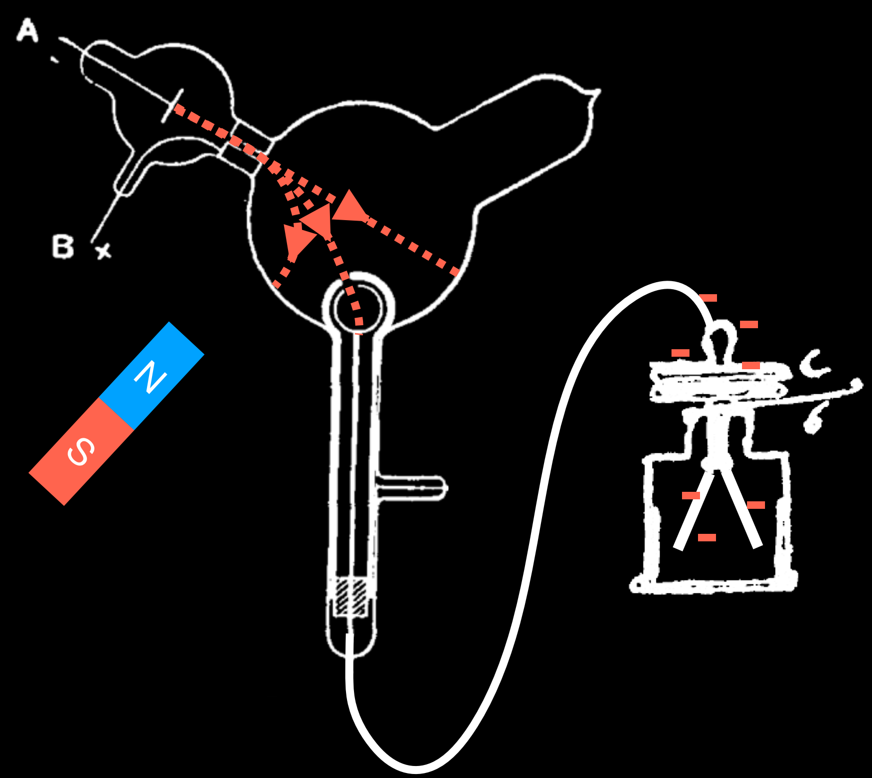

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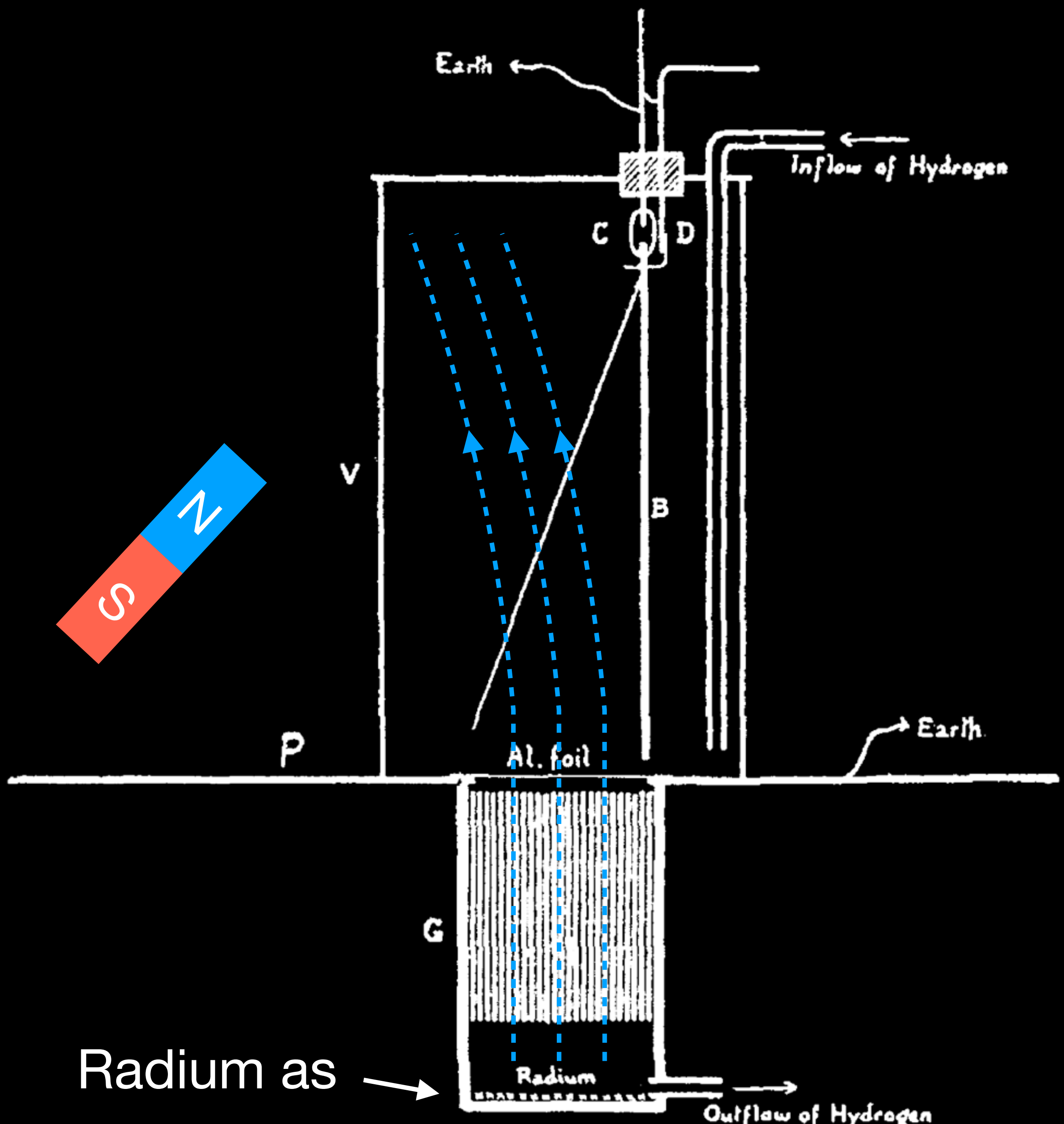

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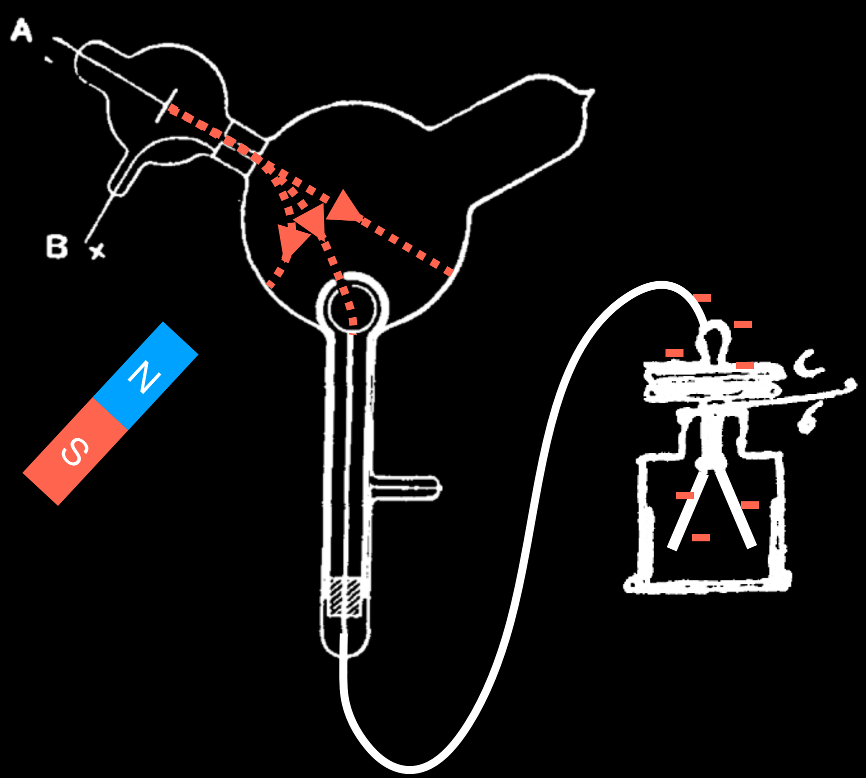

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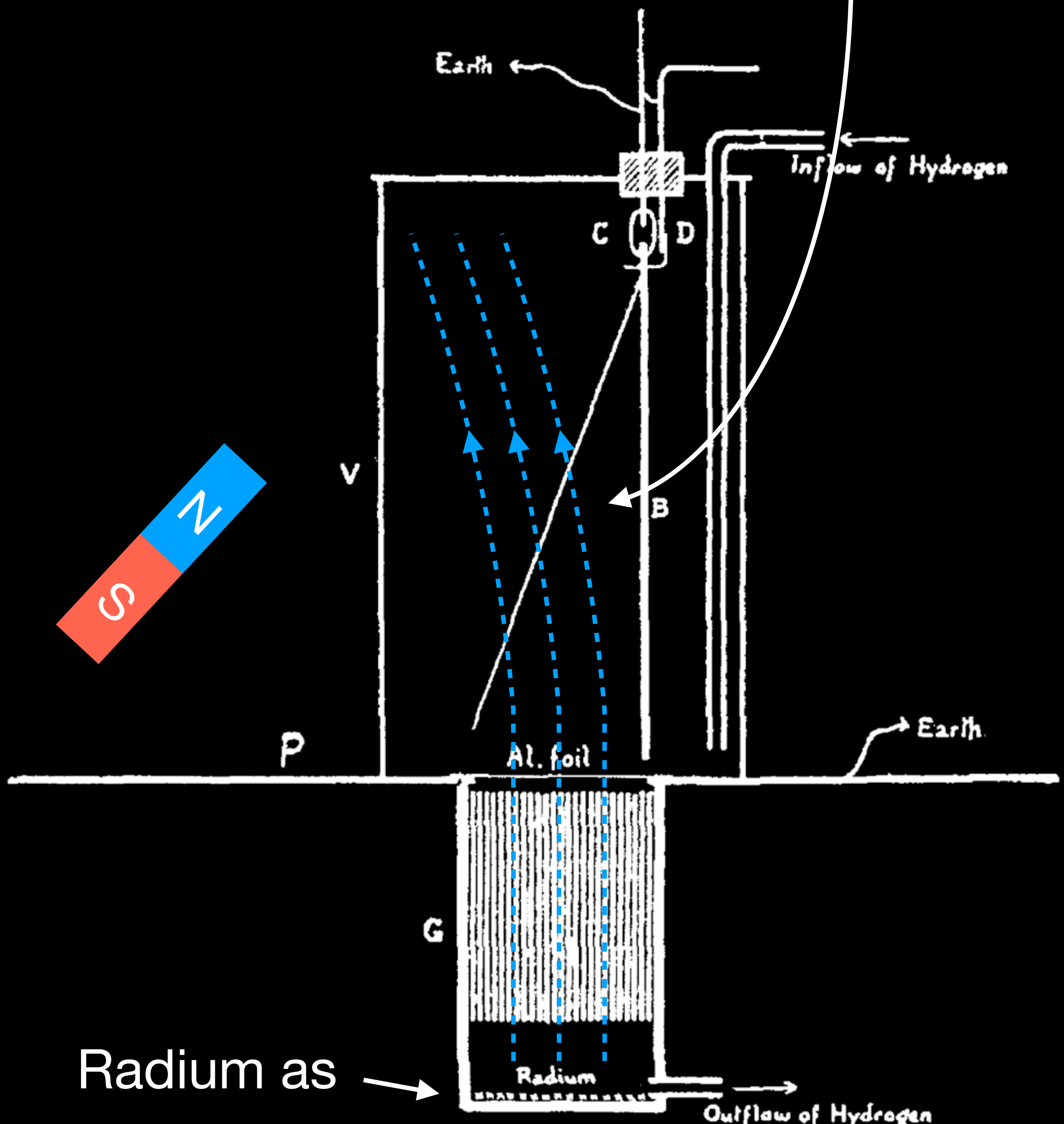
Ionization chamber



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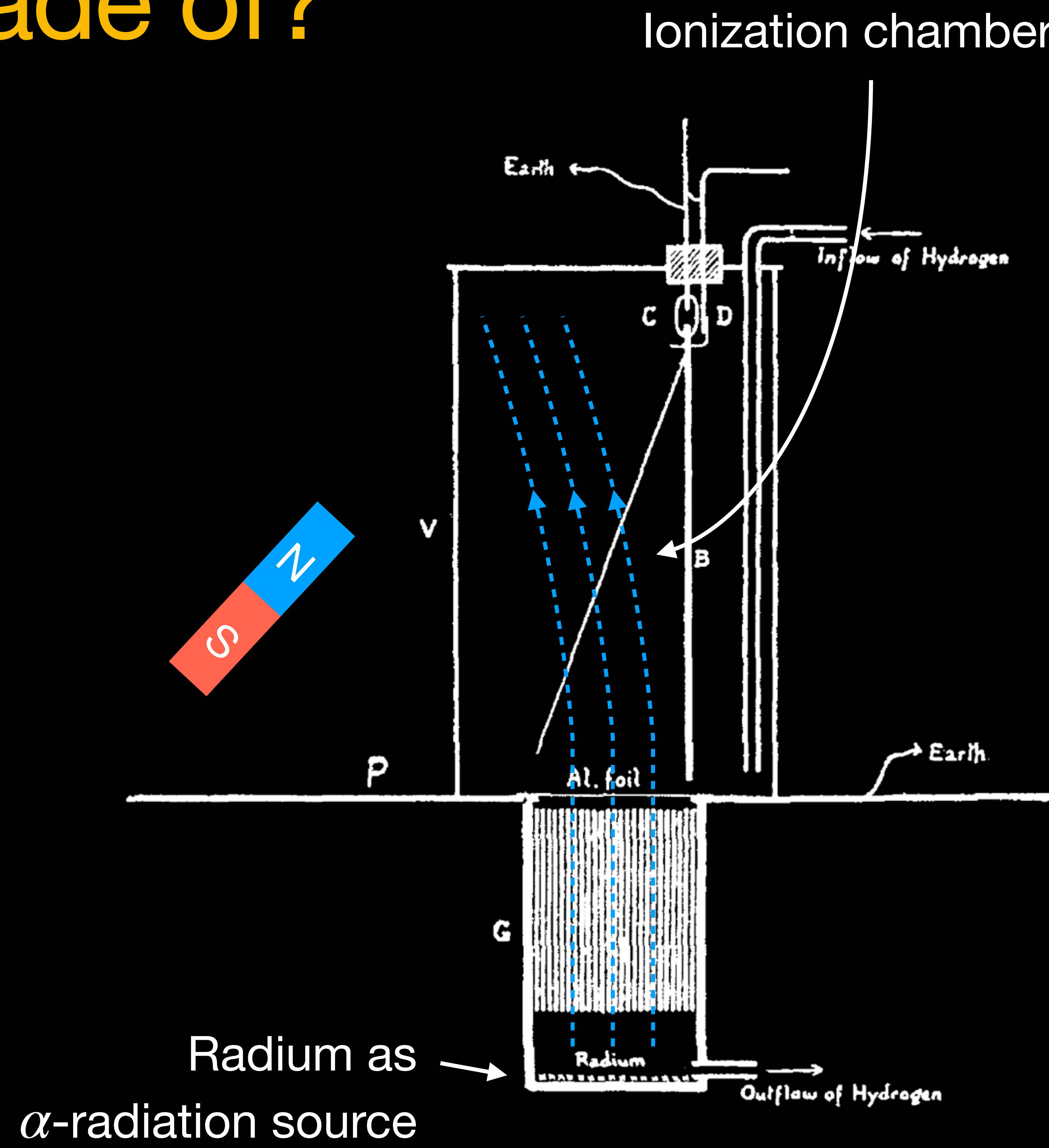

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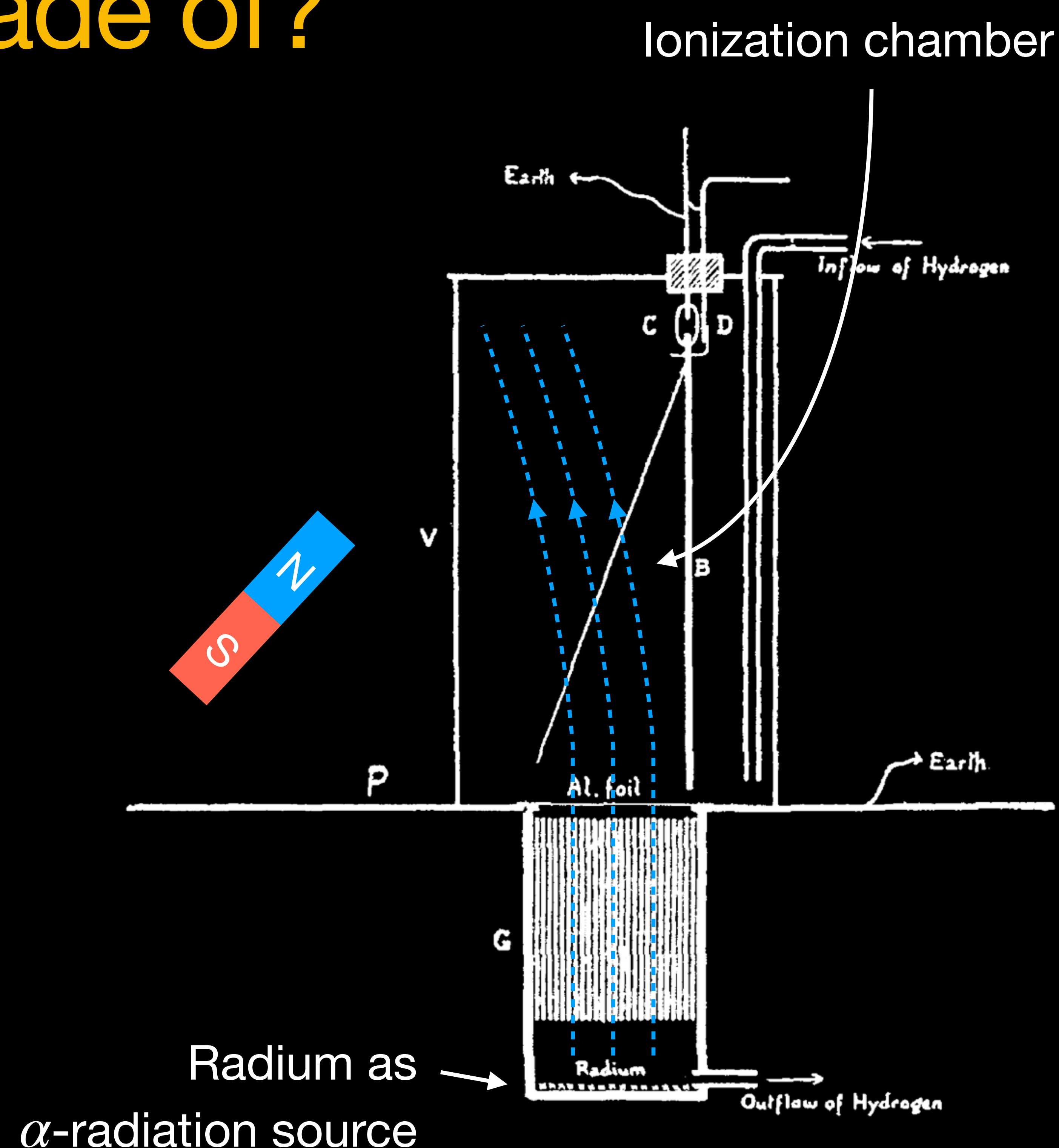
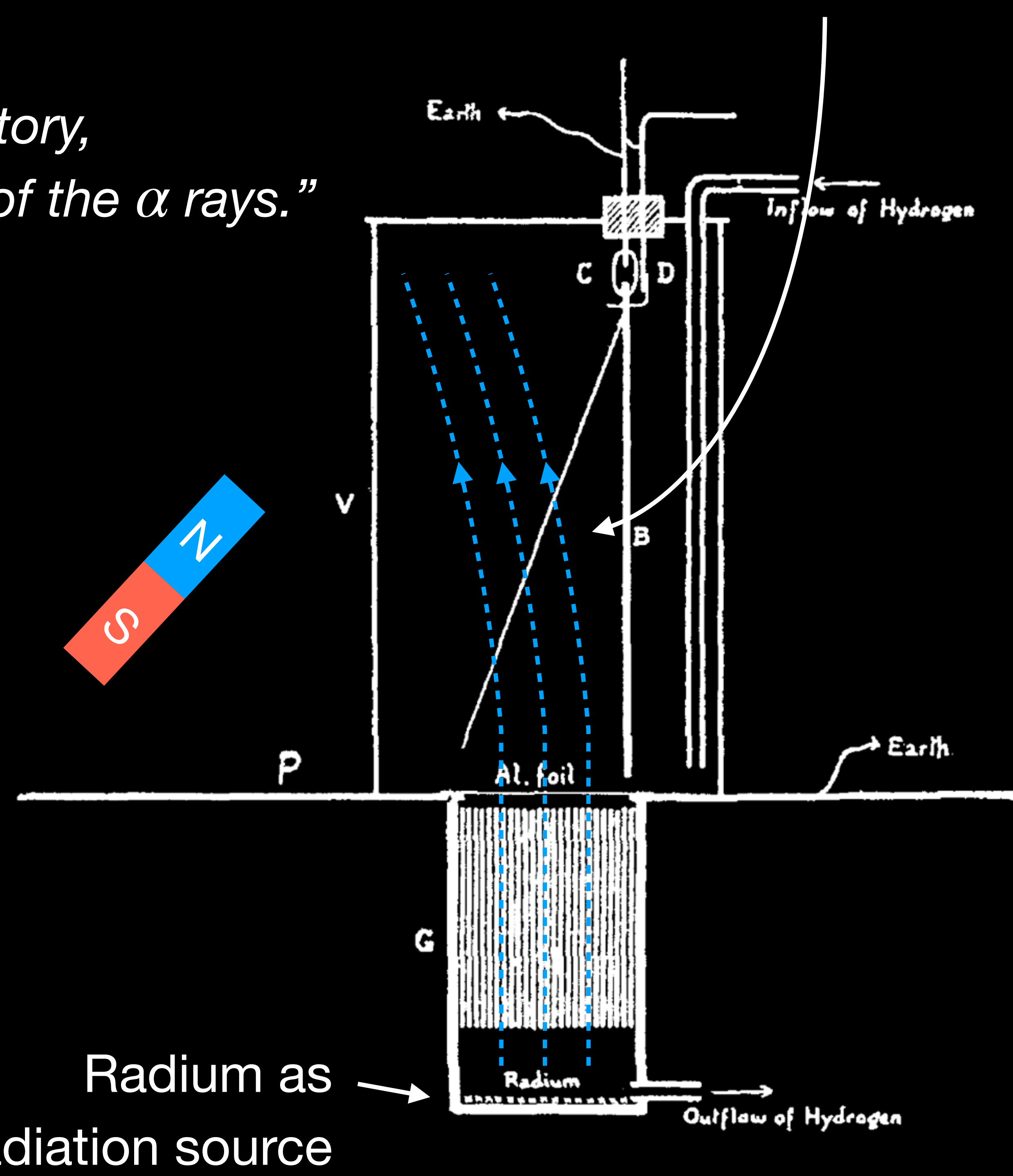


"The direction of deviation in a magnetic field was ***opposite in sense to the cathode rays****, i.e. the α* ***rays consisted of positively charged particles."***

What are α rays made of?

"With the largest electromagnet in the laboratory,
I was only able to deviate about 30 per cent of the α rays."



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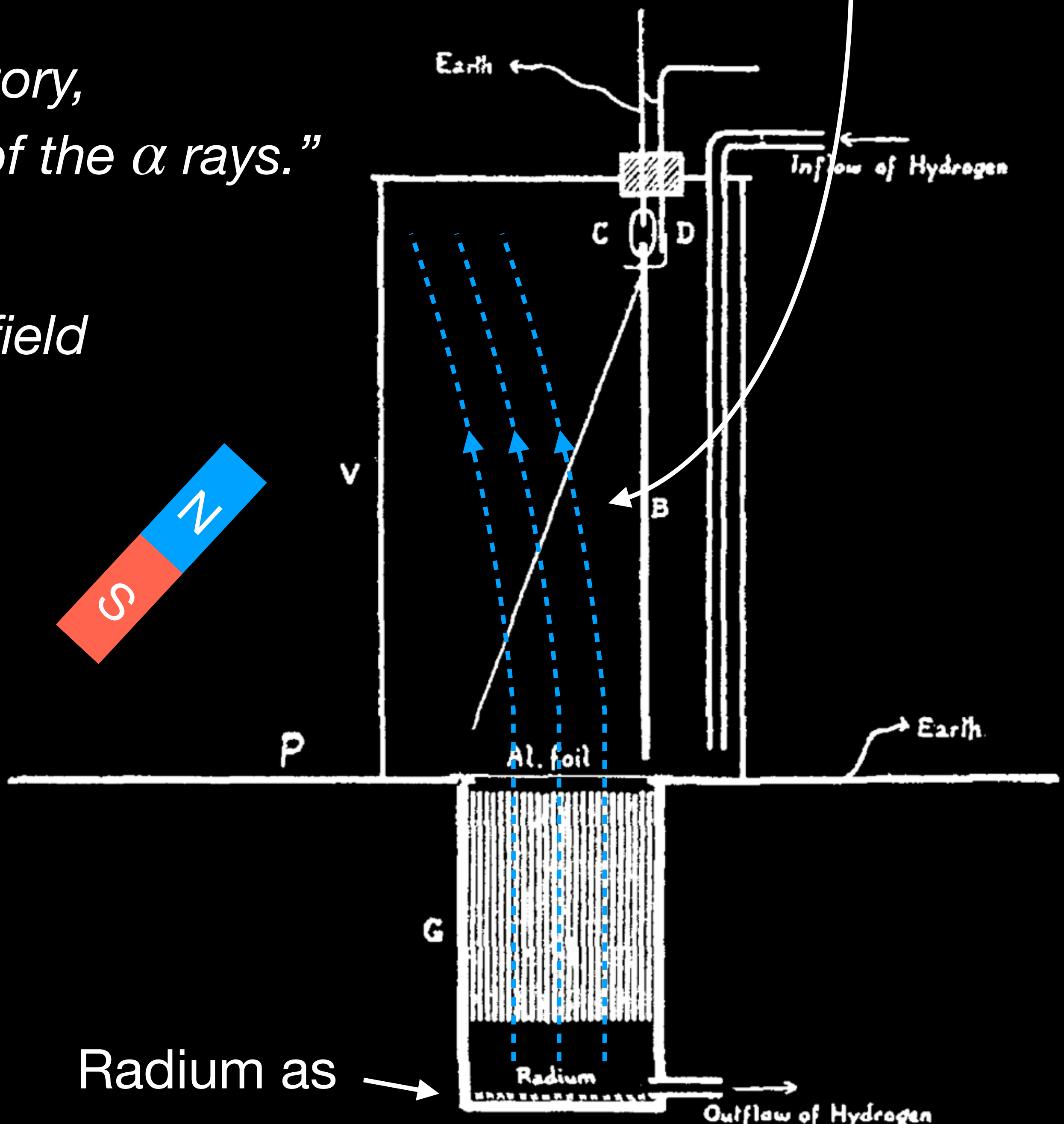
Ionization chamber



Radium as α-radiation source

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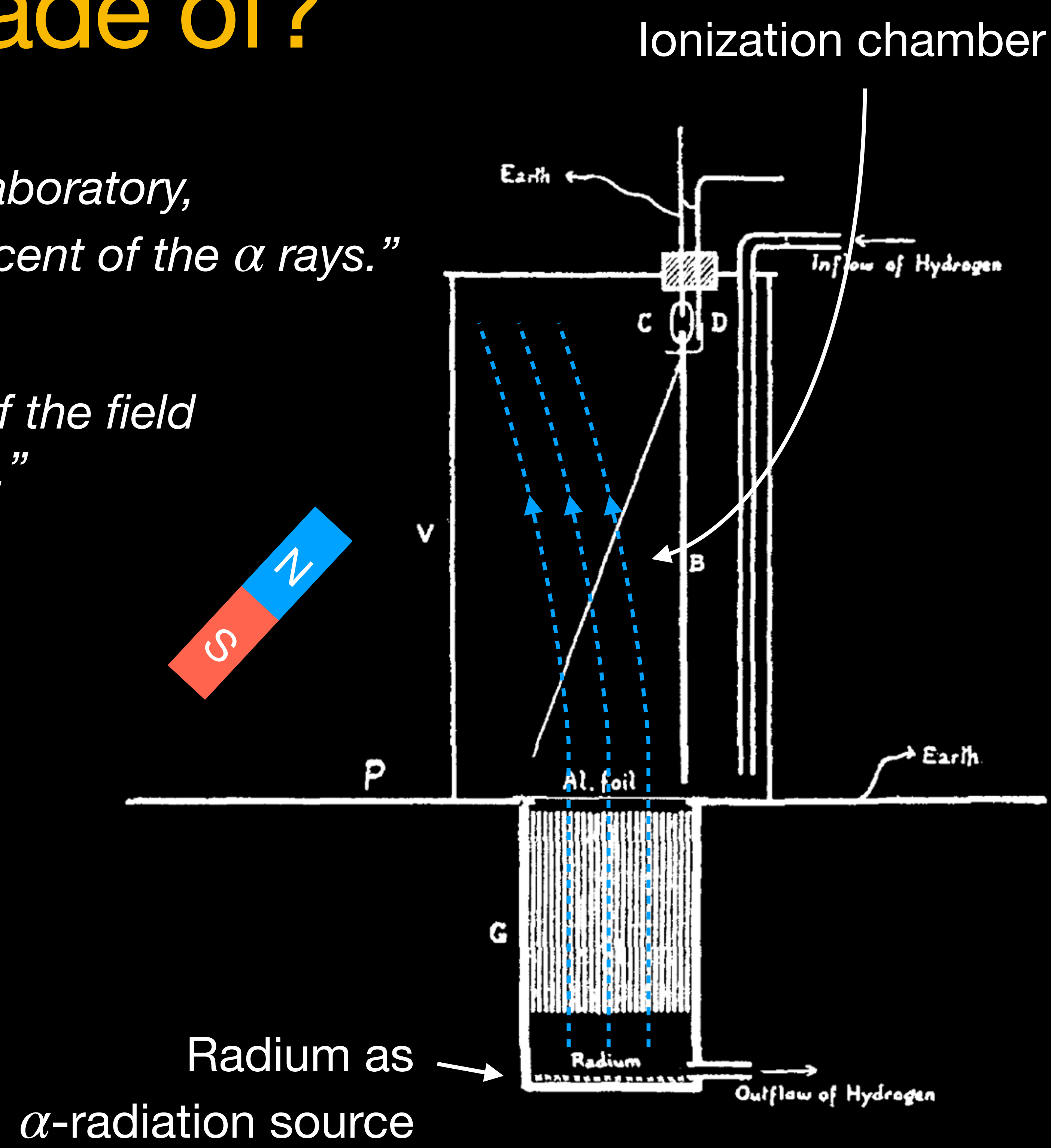
Radium already used as a tool for research!



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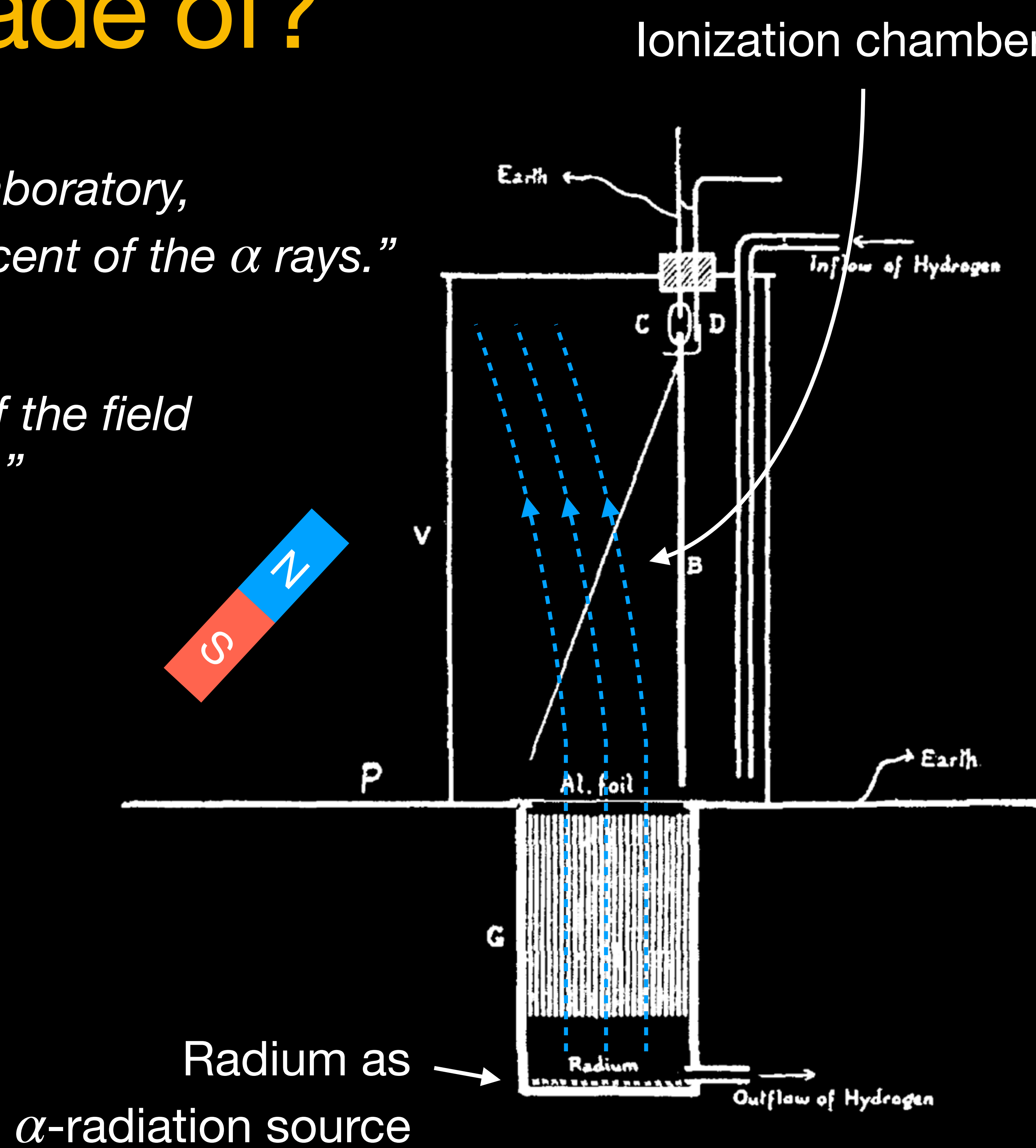
"The sample of radium of greater activity than that normally sold was obtained through the kindness of M. Curie"



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1903: Three kinds of radioactivity

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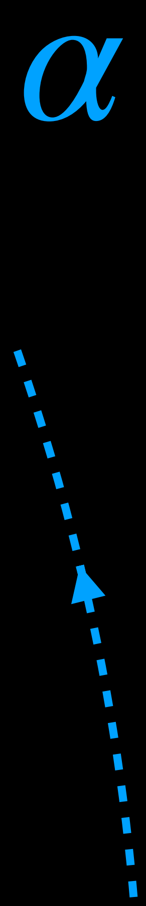
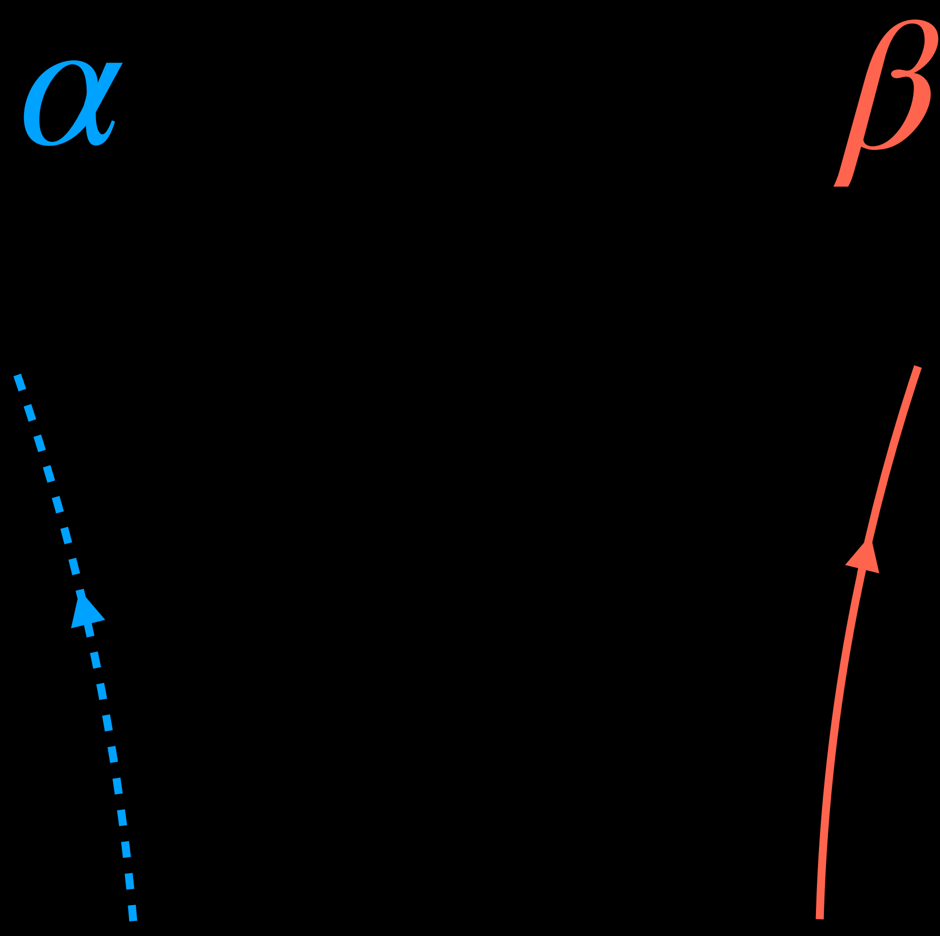


Positively charged

high m/e

easily stopped

1903: Three kinds of radioactivity



Positively charged	Negatively charged
high m/e	small m/e
easily stopped	more penetrating

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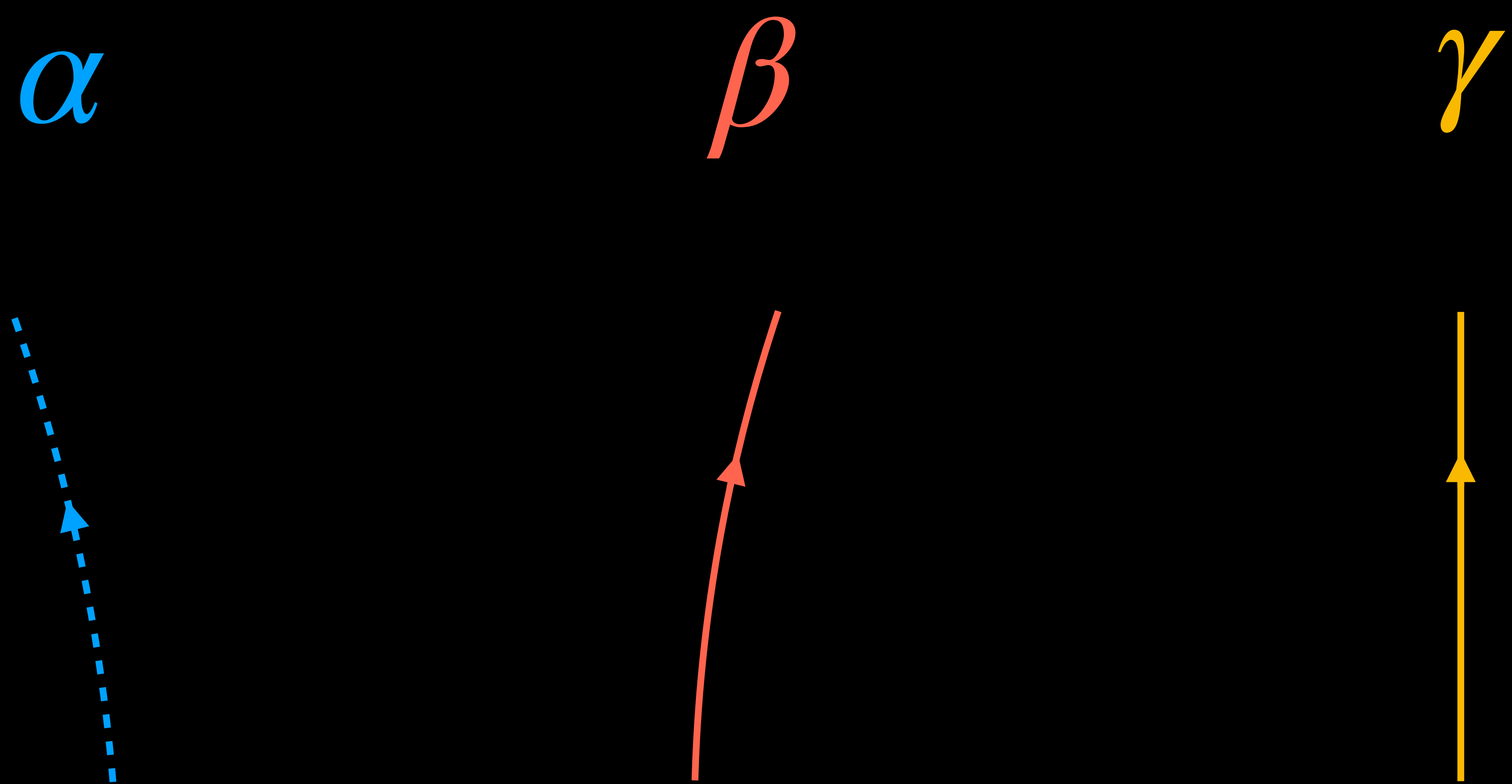
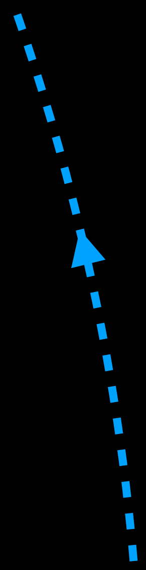
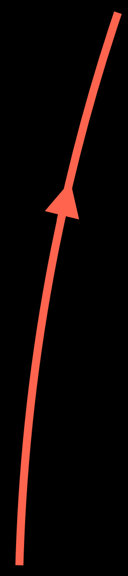


Positively charged	Negatively charged	Uncharged
high m/e	small m/e	
easily stopped	more penetrating	even more penetrating

1903: Three kinds of radioactivity

α β γ





Paul Villard

Chemist and Physicist in Paris

α	β	γ
Positively charged	Negatively cl	charged
high m/e	small m	
easily stopped	more penetrating	even more penetrating

Moving to Manchester

An offer he could not refuse …

Moving to Manchester

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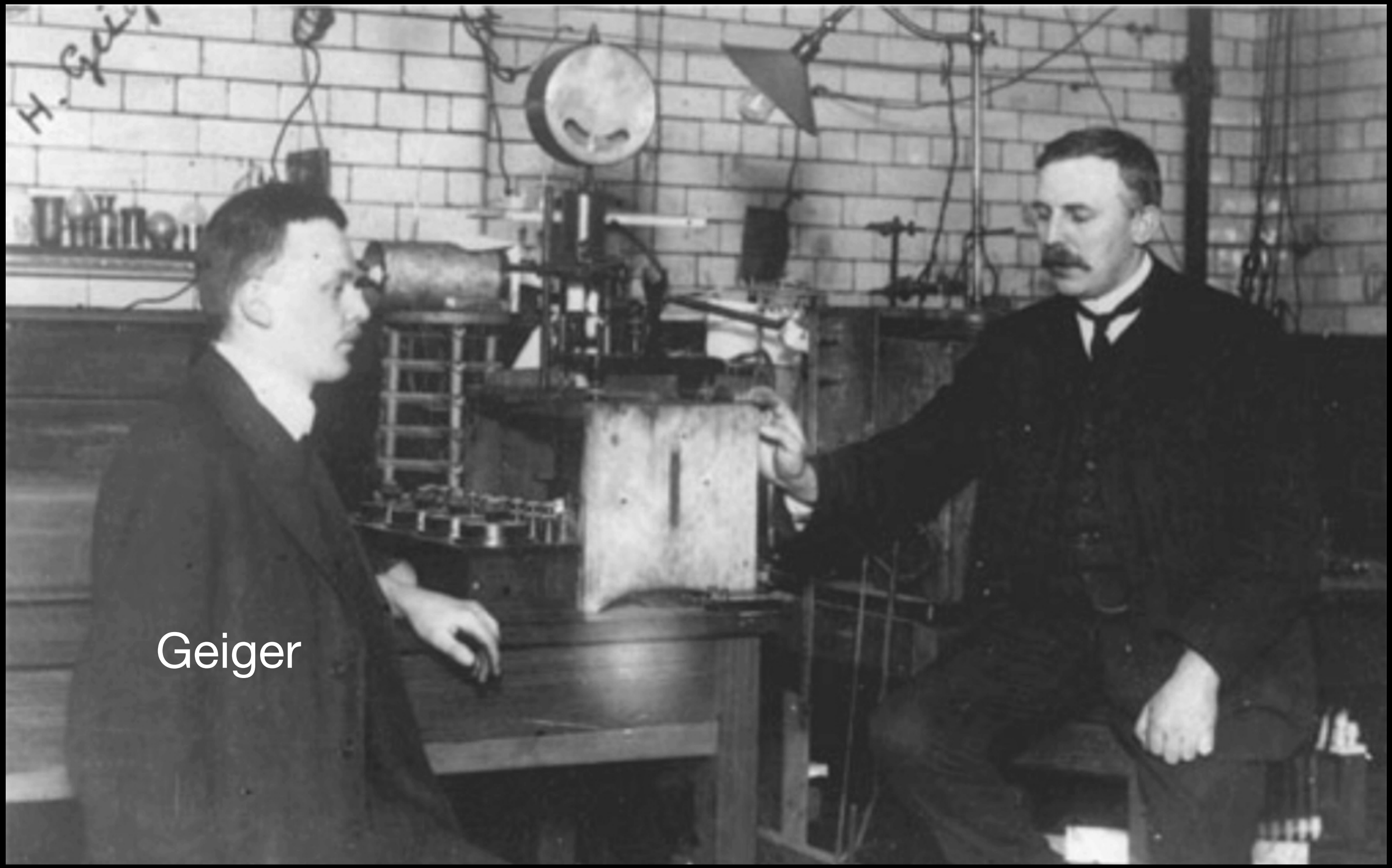

Moving to Manchester

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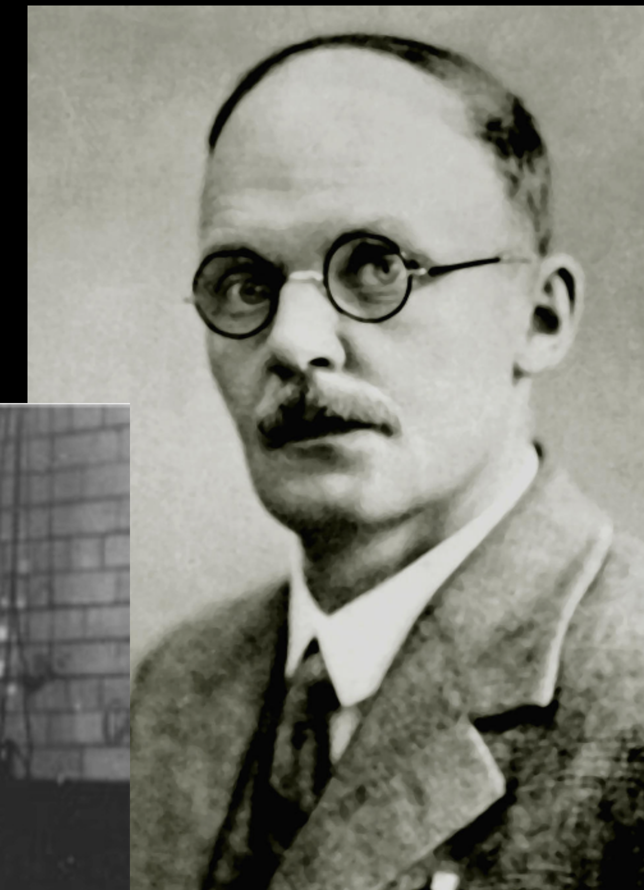

Hans Geiger

Moving to Manchester

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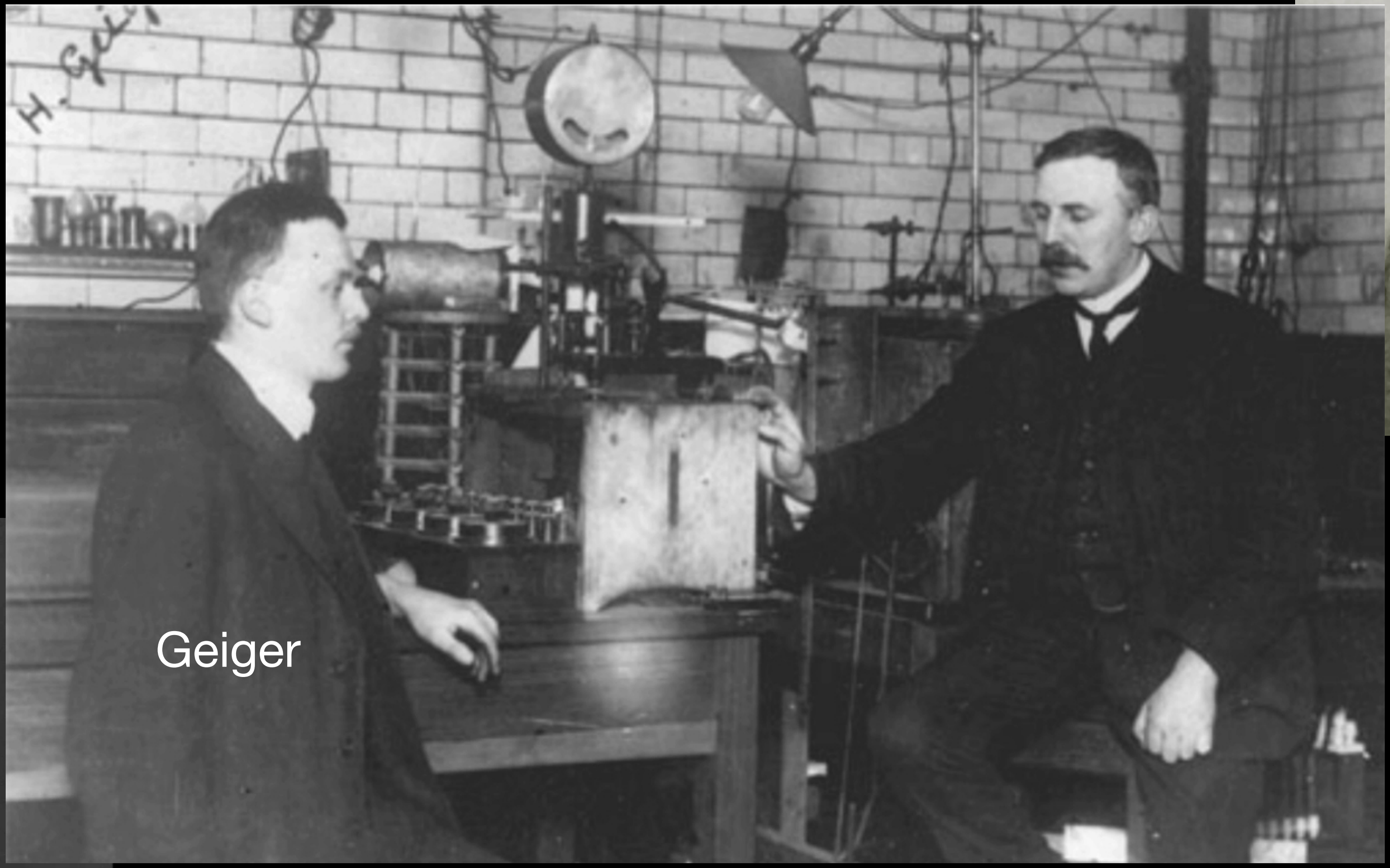

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Moving to Manchester

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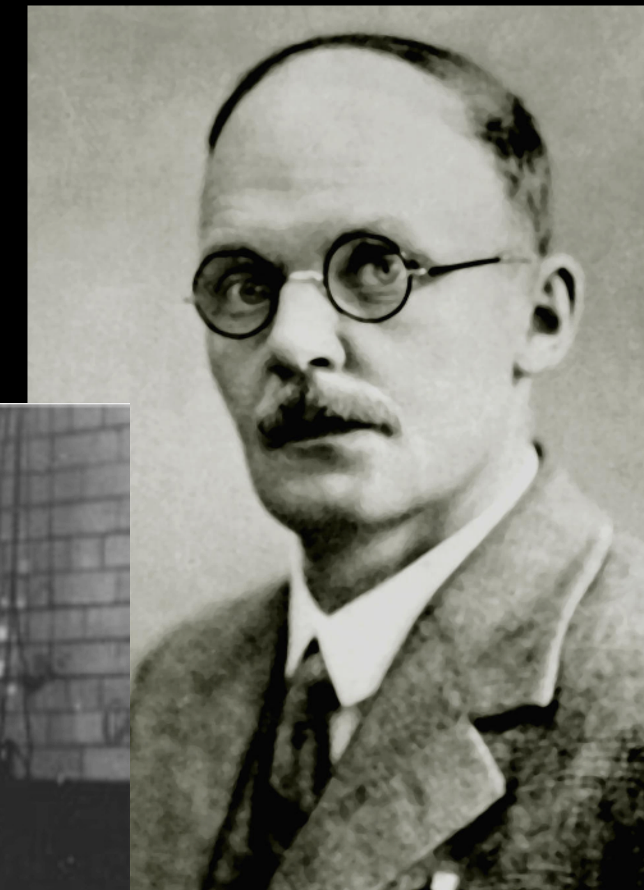

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“Everybody seems jolly & anxious to help and I find a most enjoyable absence of convention.”

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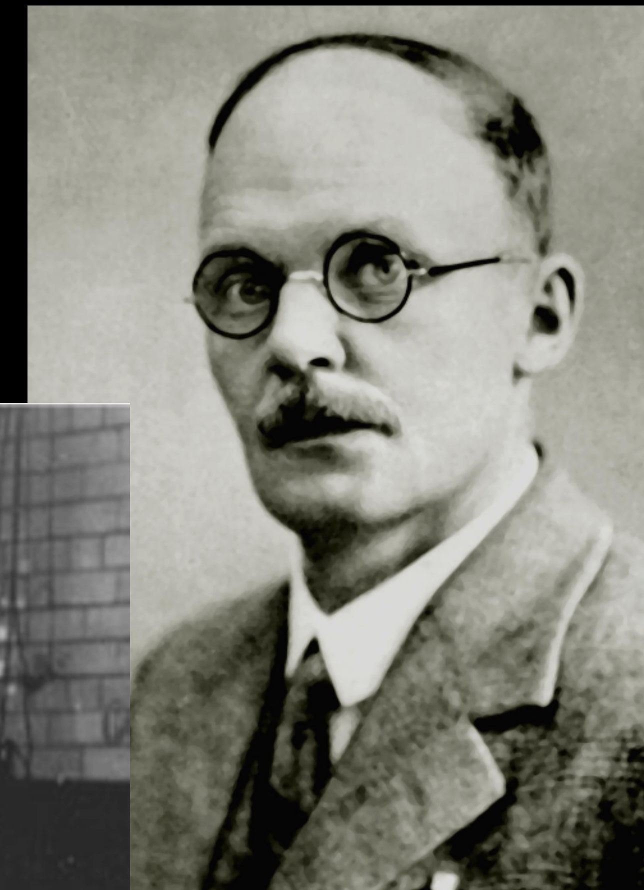


Hans Geiger

Ernest Marsden

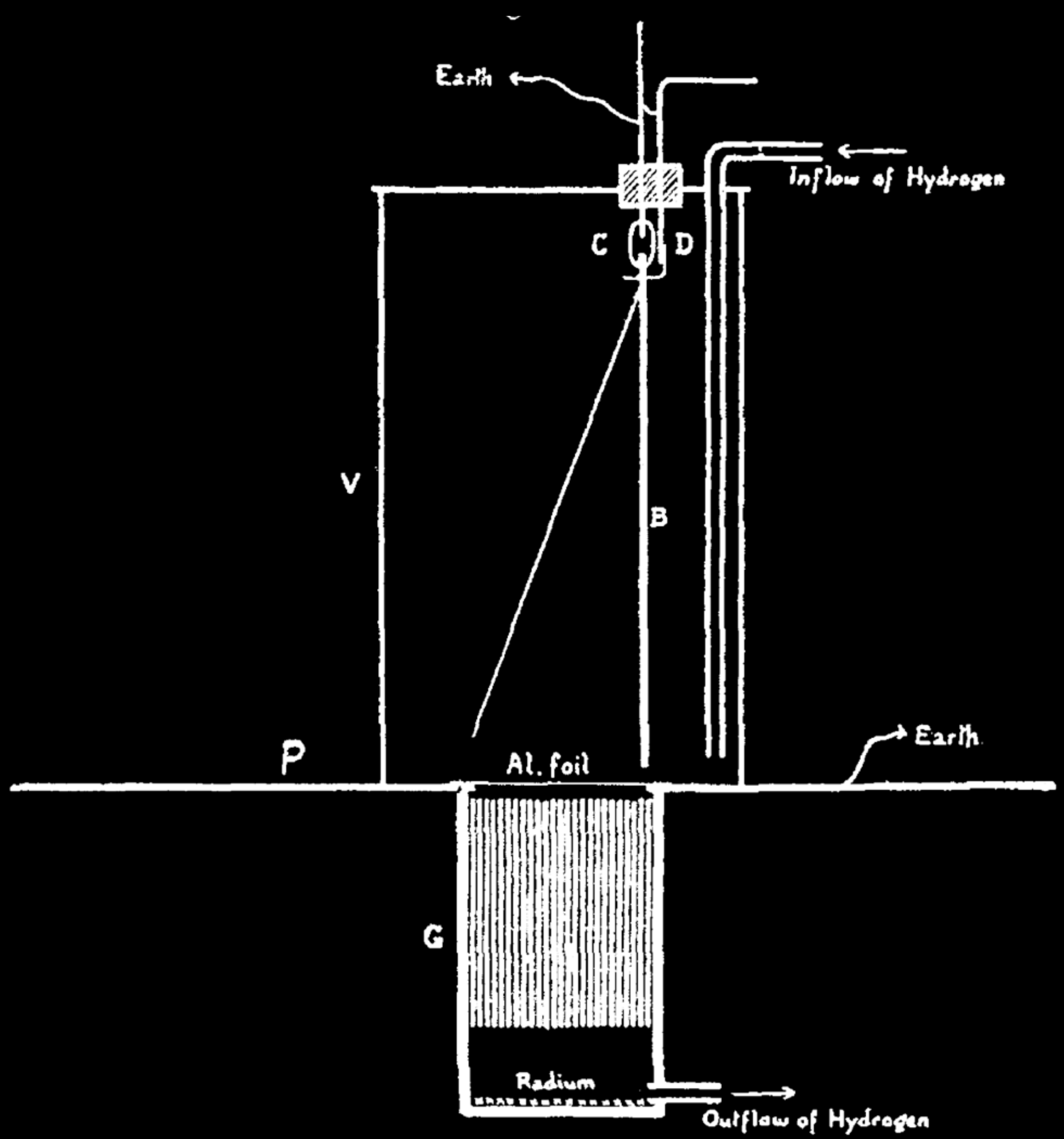
"Everybody seems jolly & anxious to help and I find a most enjoyable absence of convention."

"I find the students here regard a professor as little short of Lord God Almighty. It is quite refreshing after the critical attitude of the Canadian students."

New instruments

New instruments

Ionization chamber



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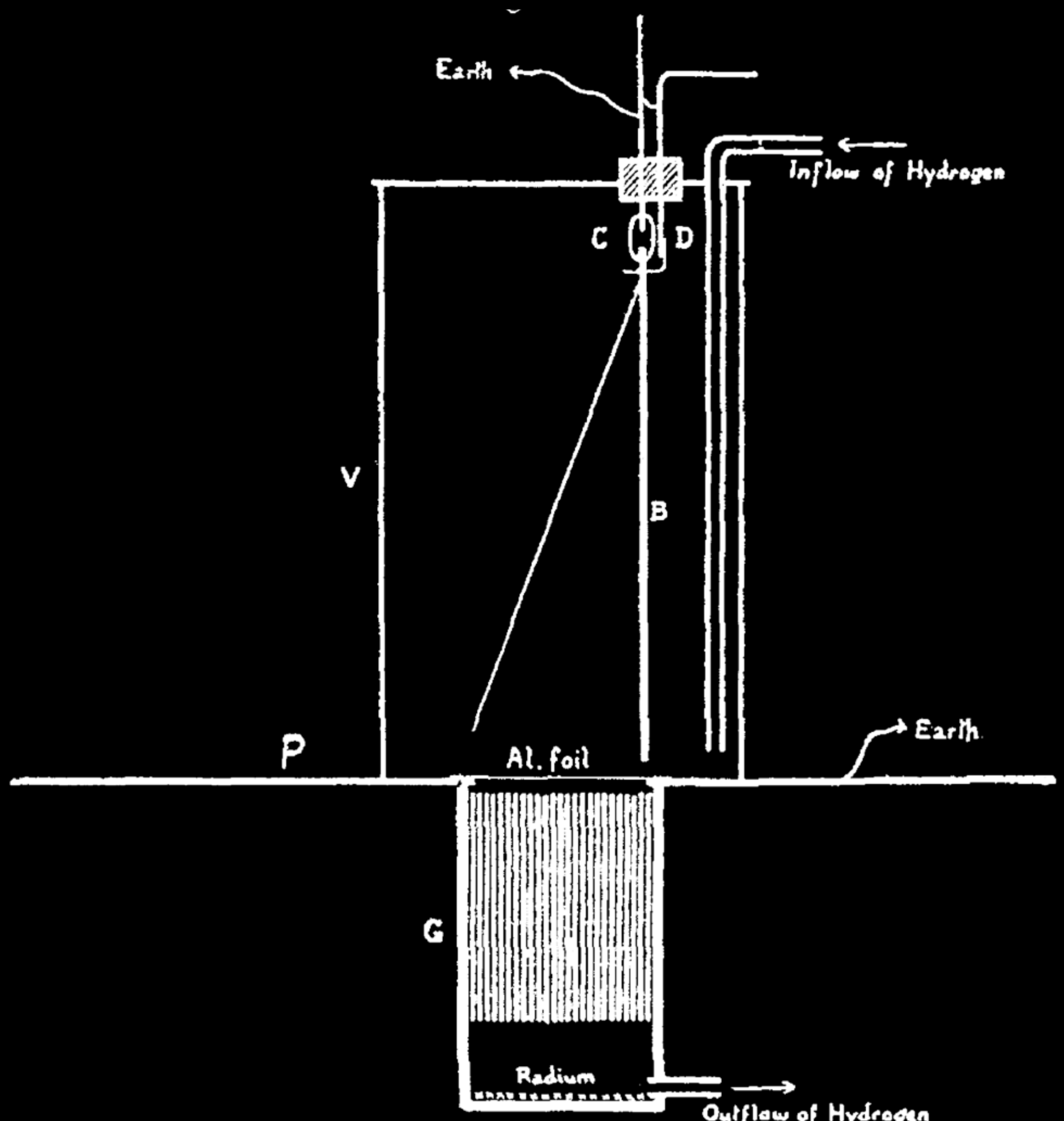
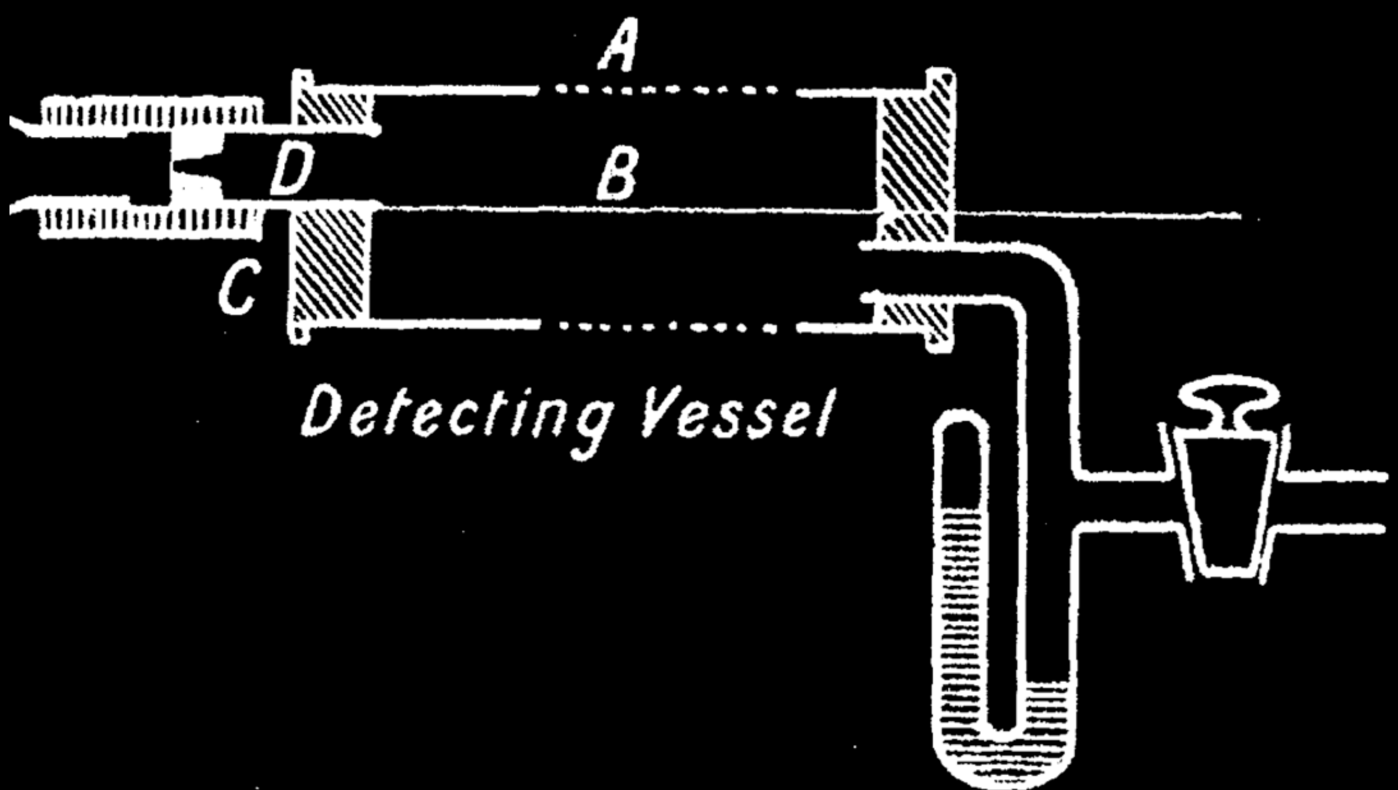
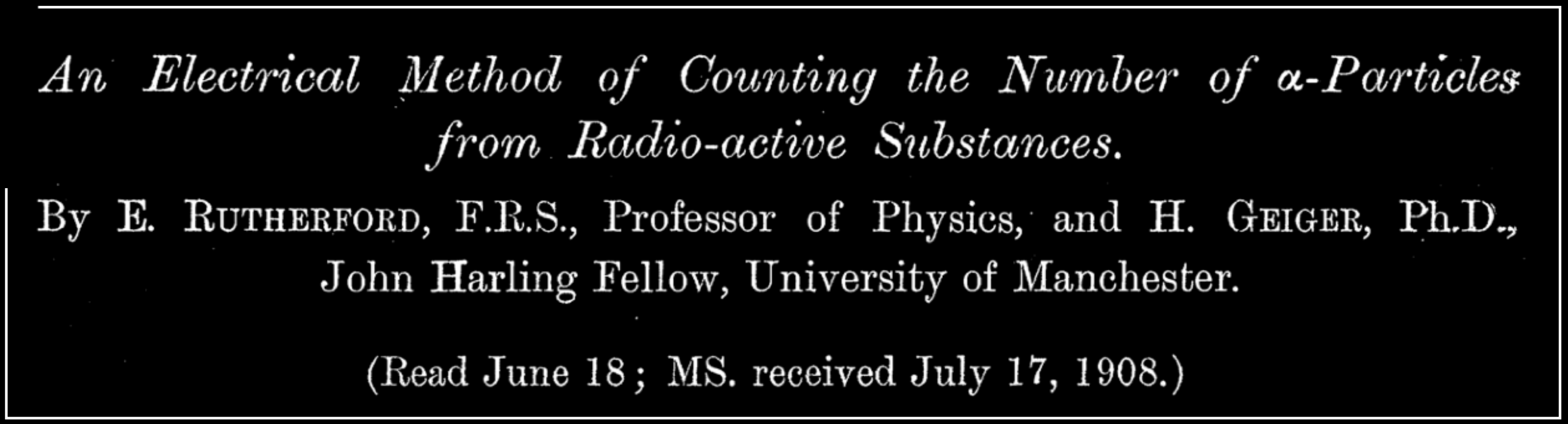


The first particle <u>counter</u>
(Rutherford and Geiger)





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By E. Rutherford, F.R.S., Professor of Physics, and H. Geiger, Ph.D., John Harling Fellow, University of Manchester.

(Read June 18; MS. received July 17, 1908.)

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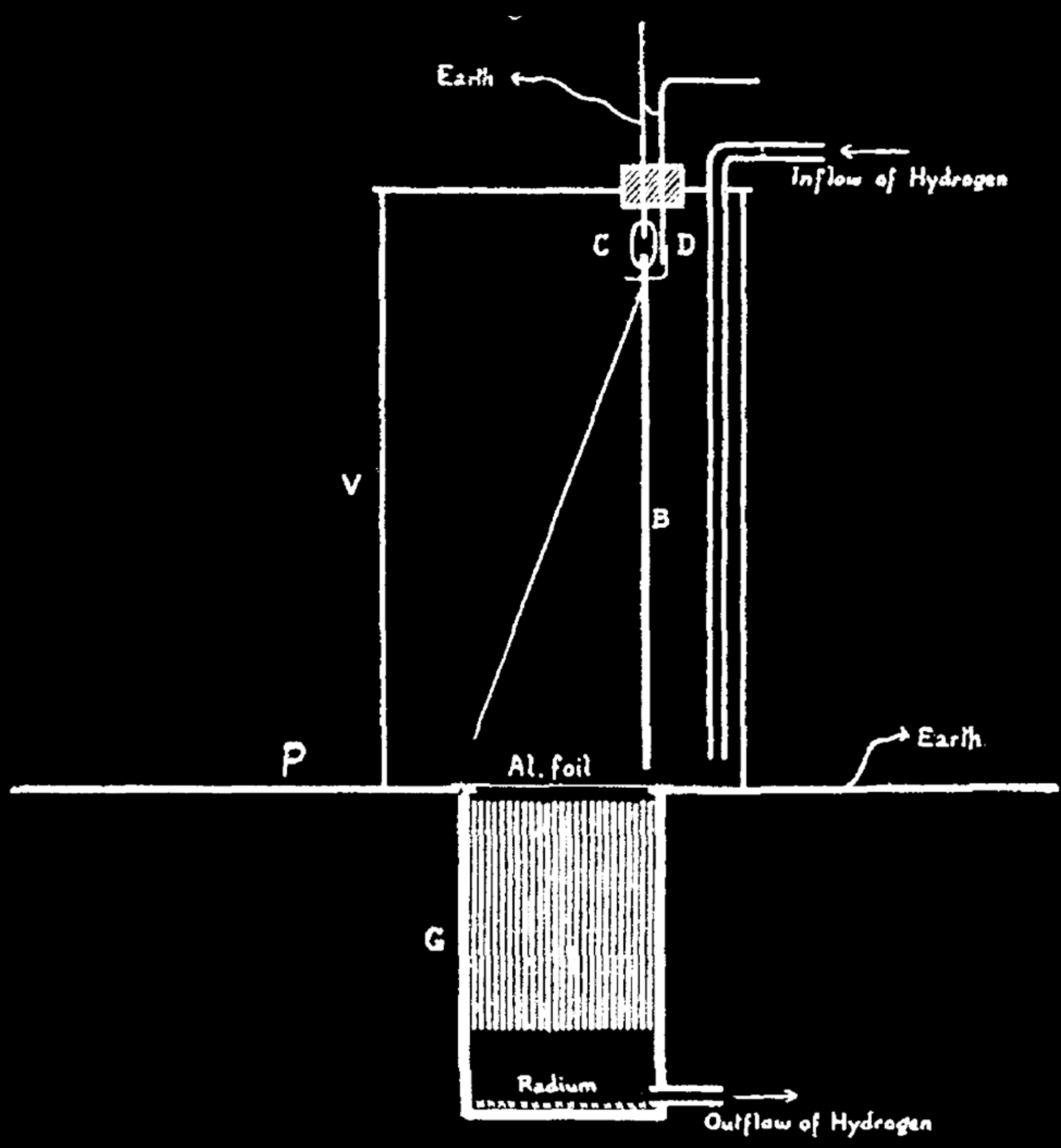

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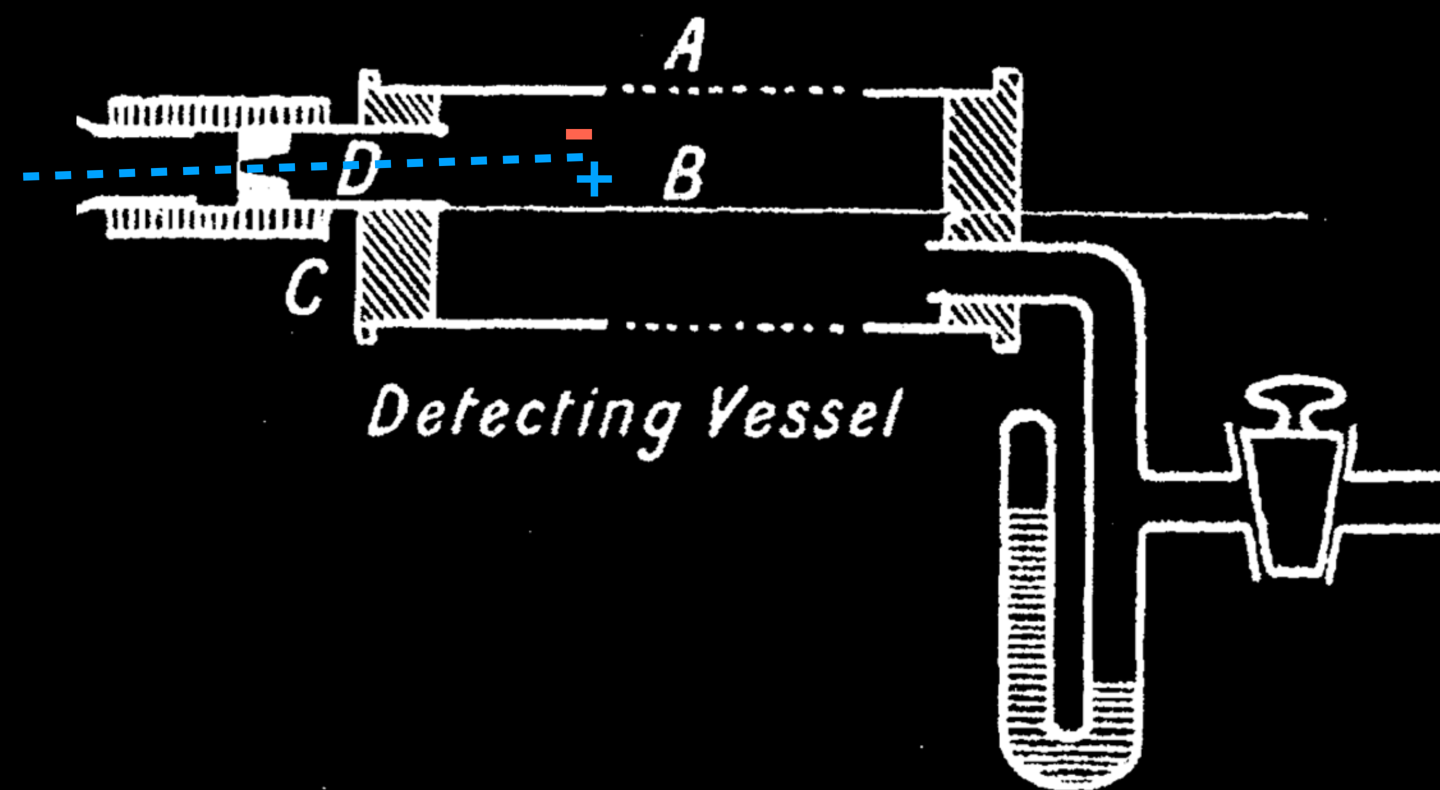

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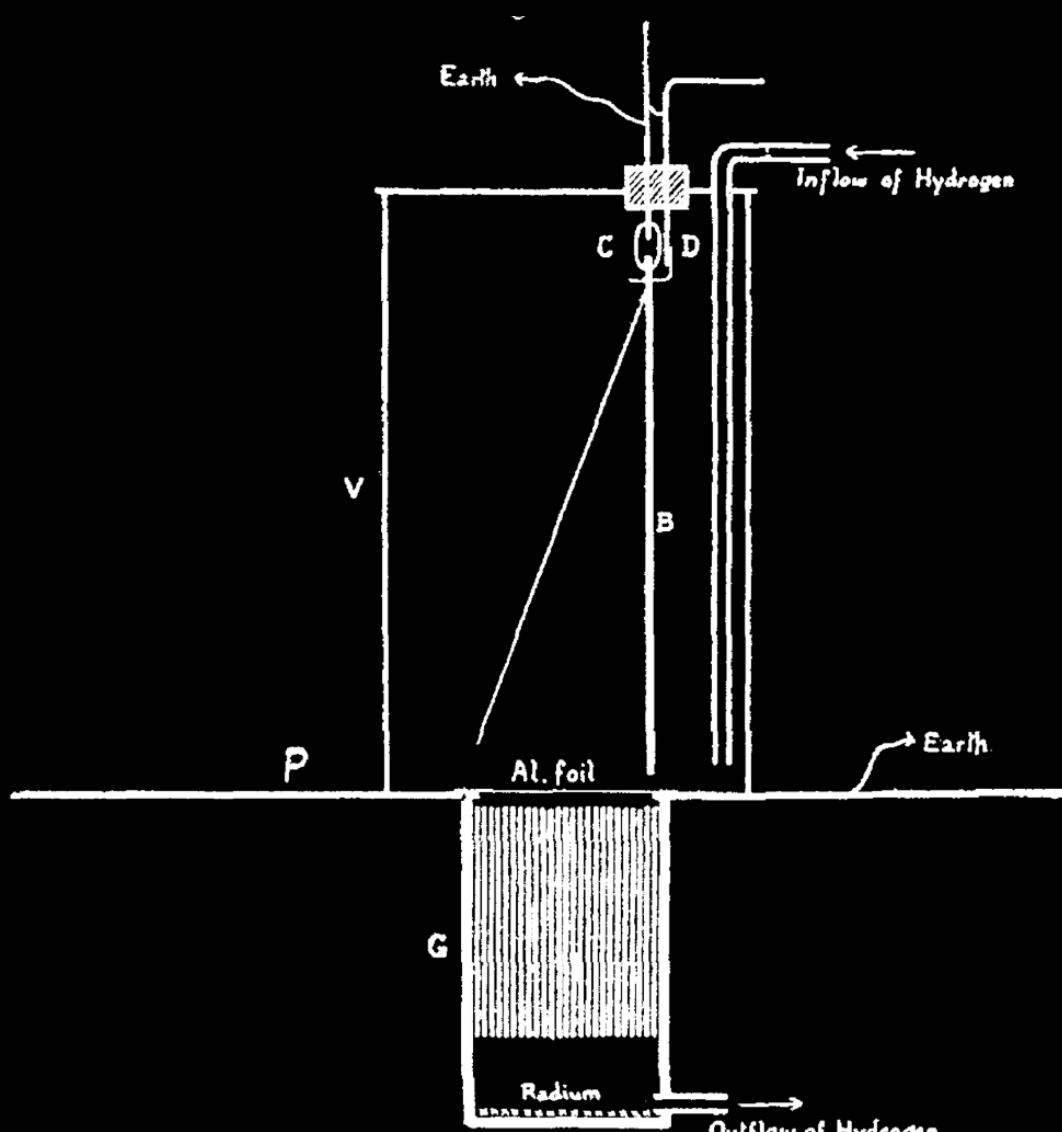

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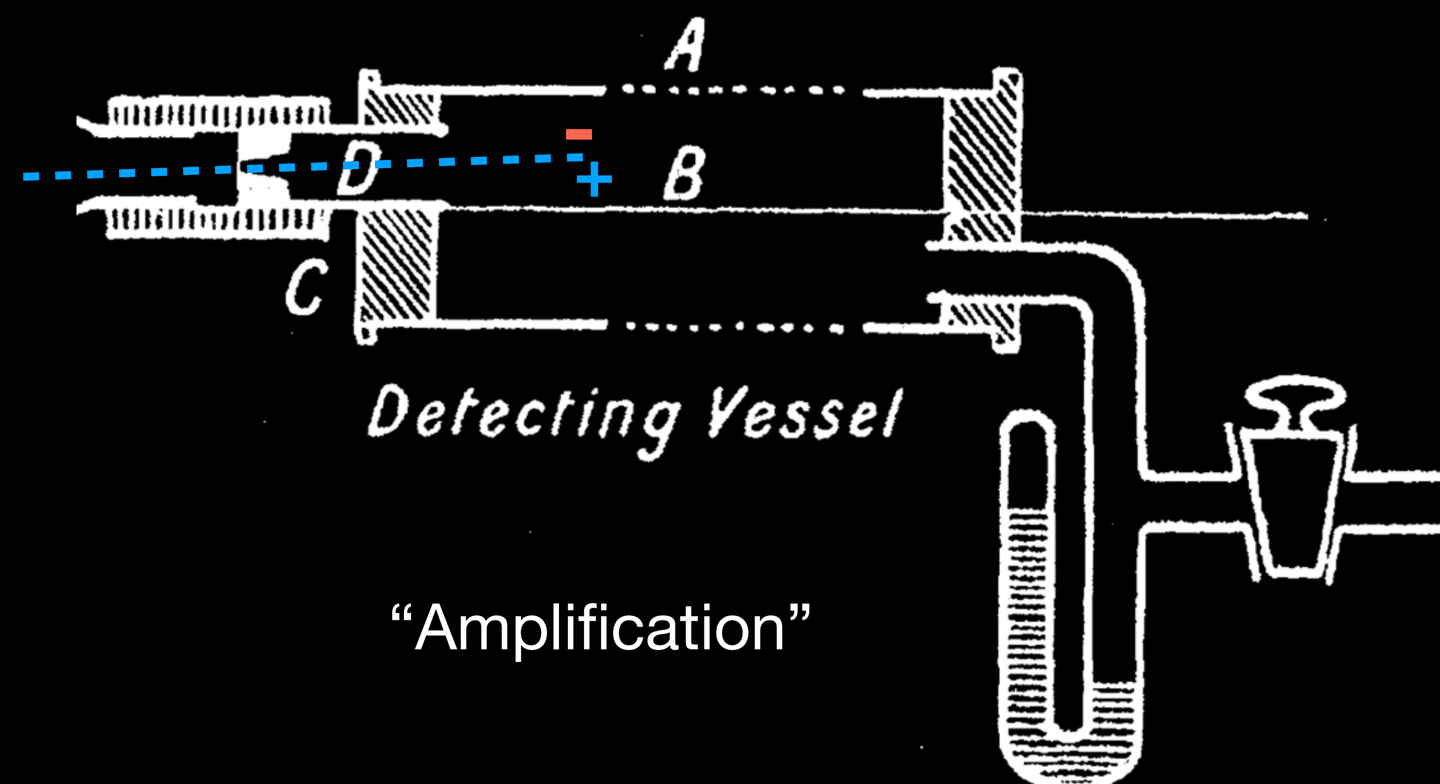

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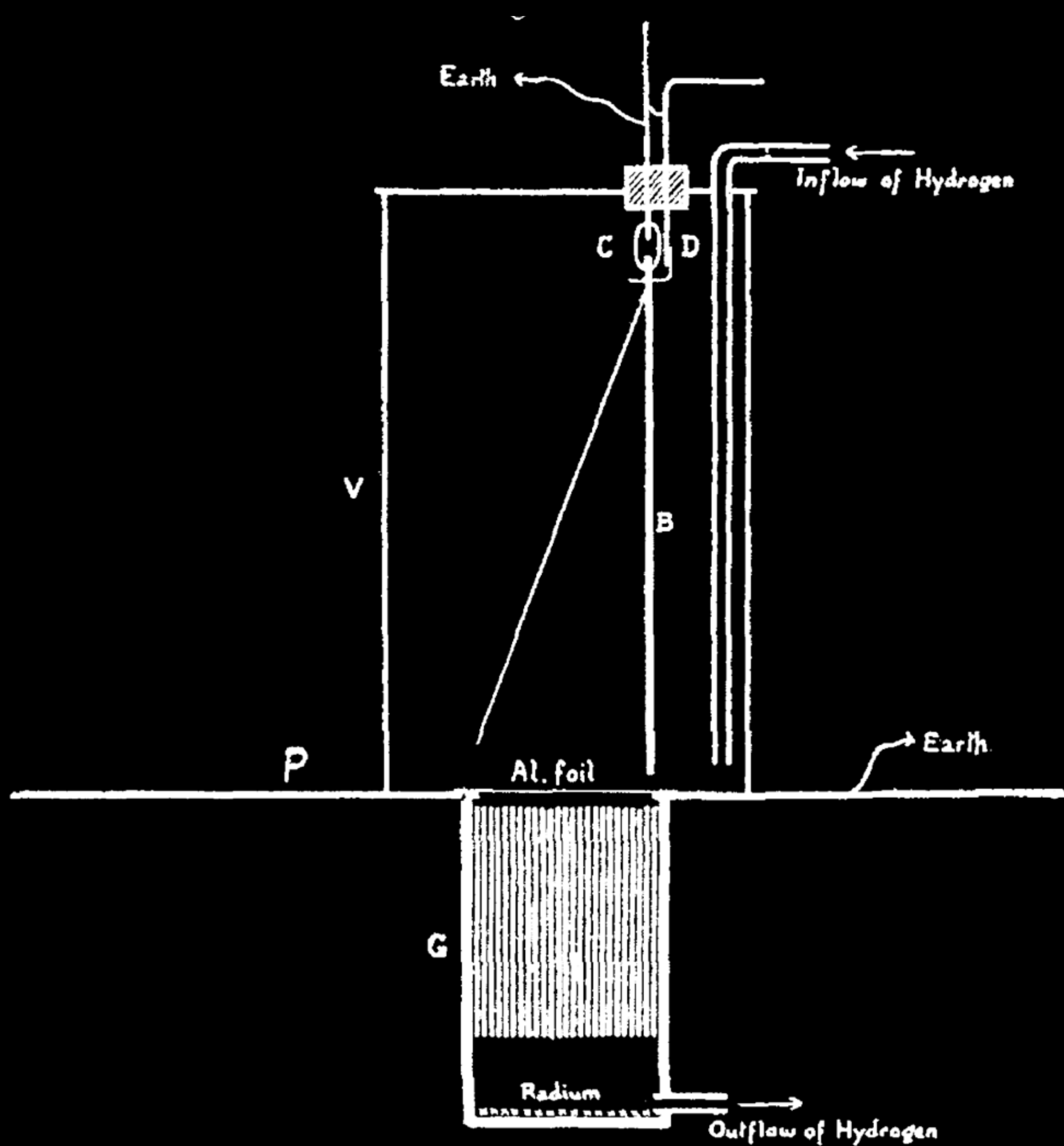

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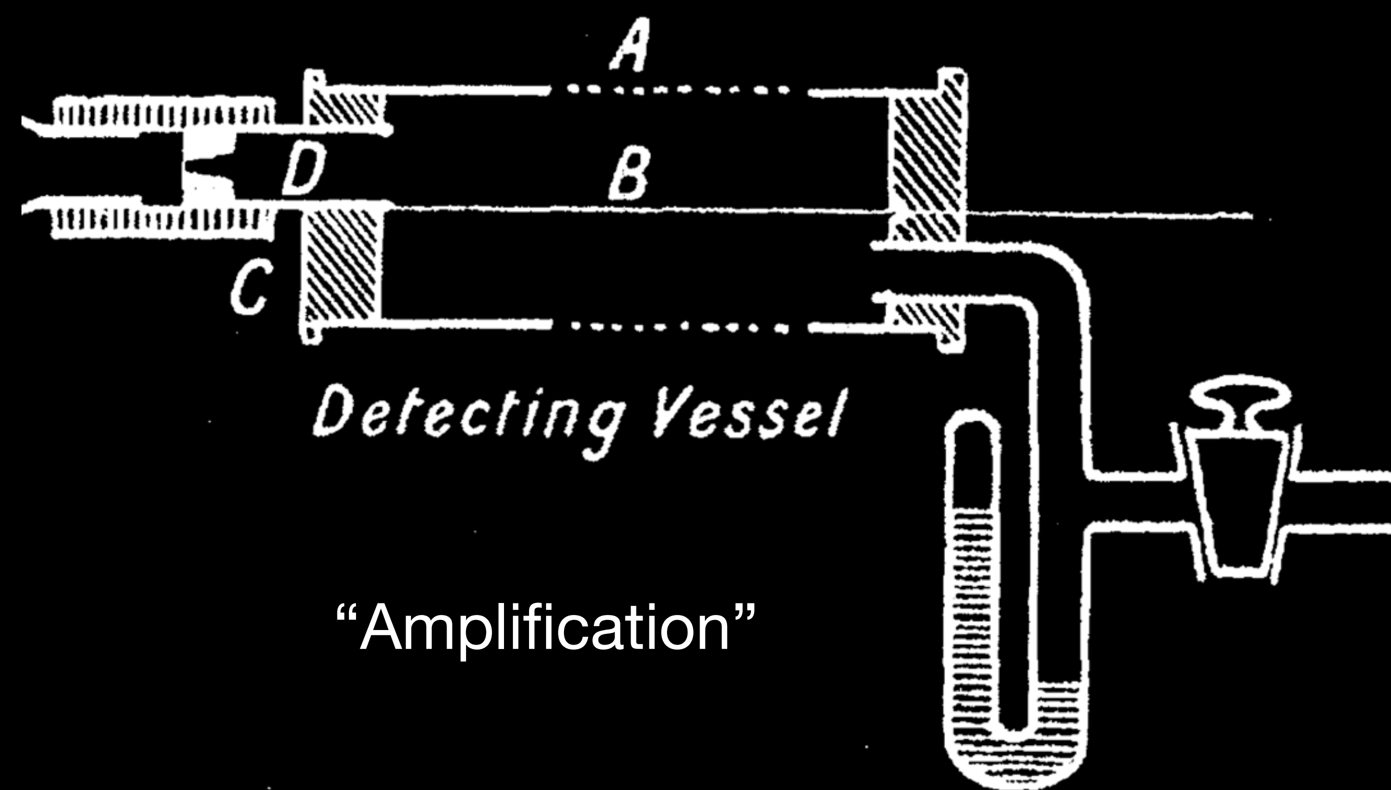

"Amplification"

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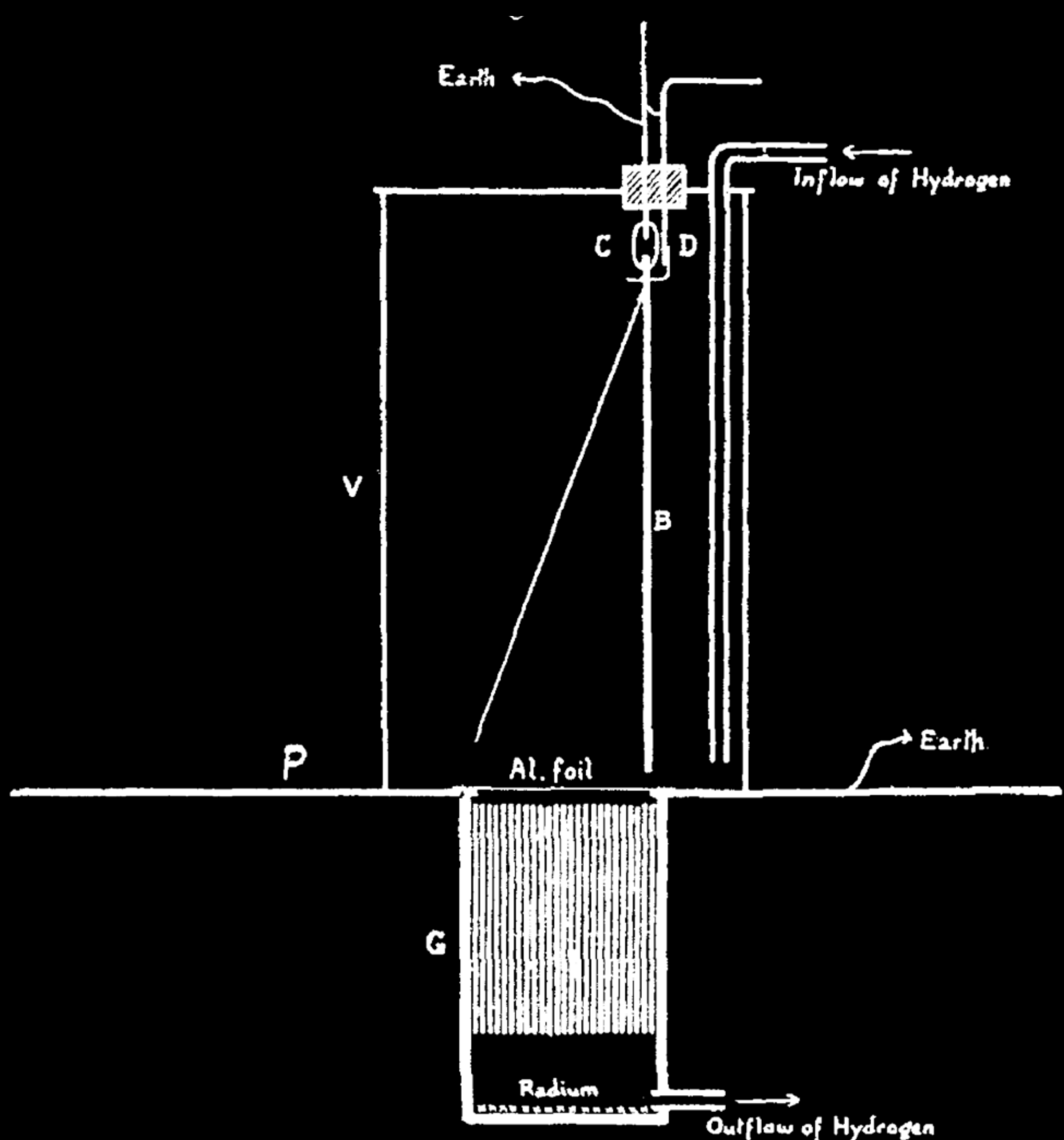

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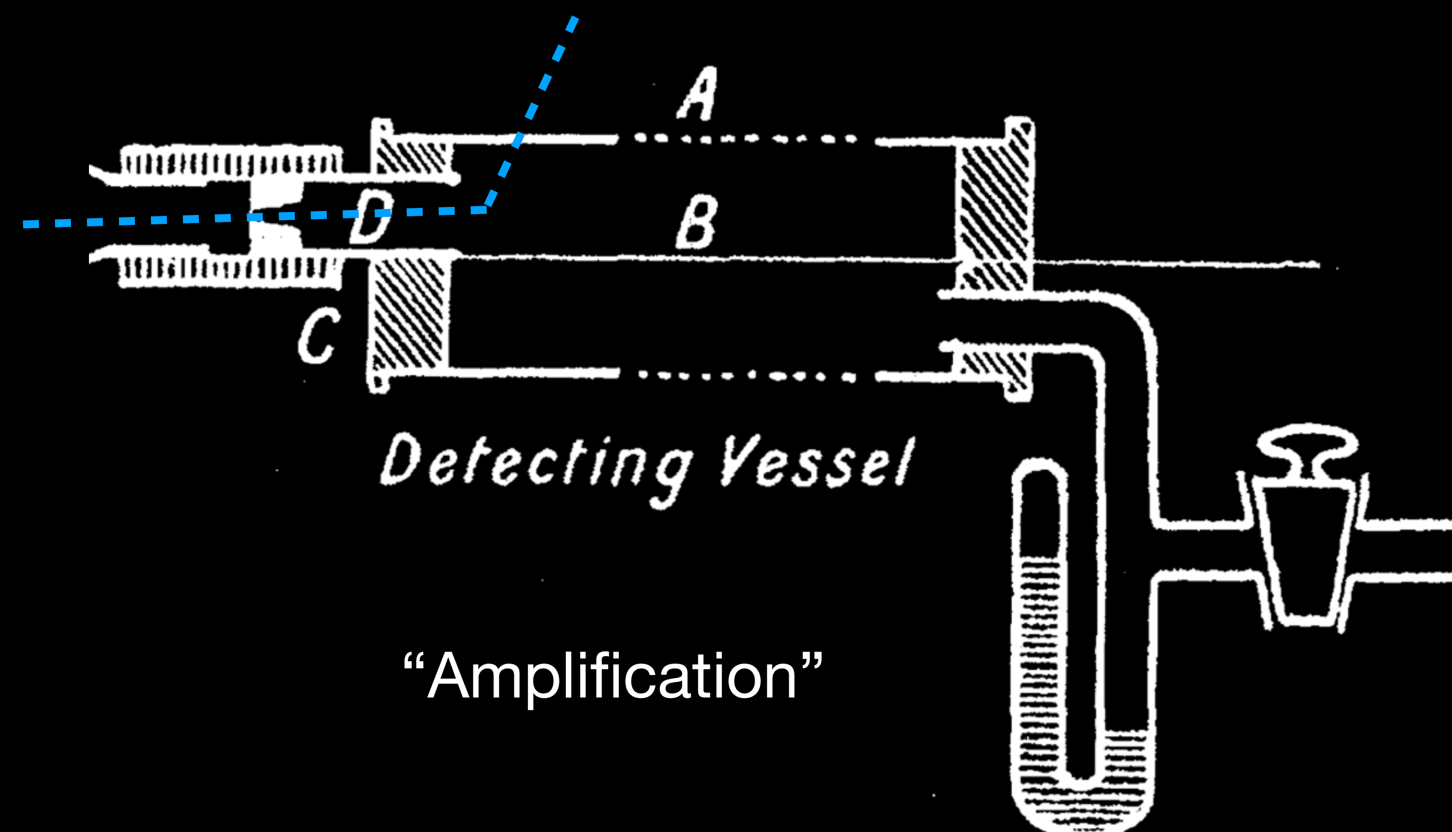

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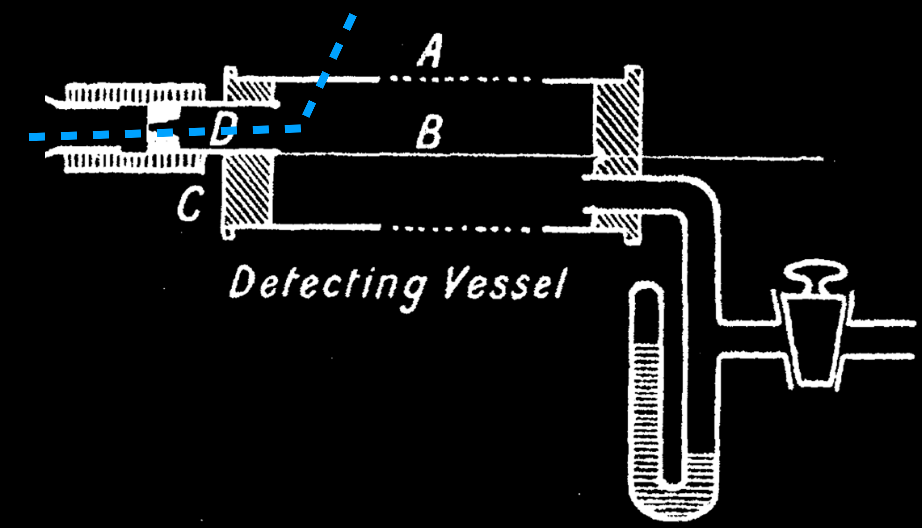
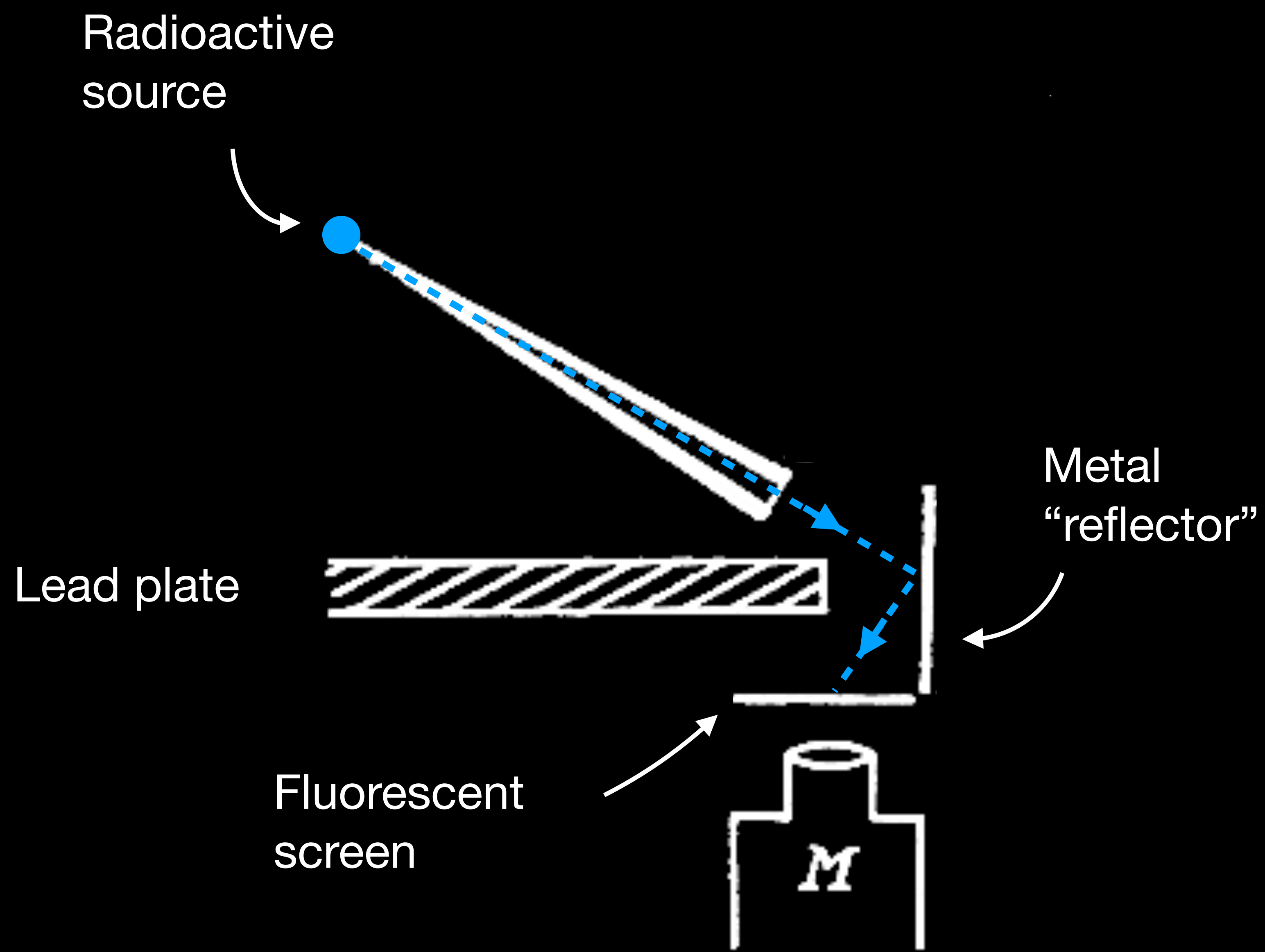
Anomalous scattering?

1909

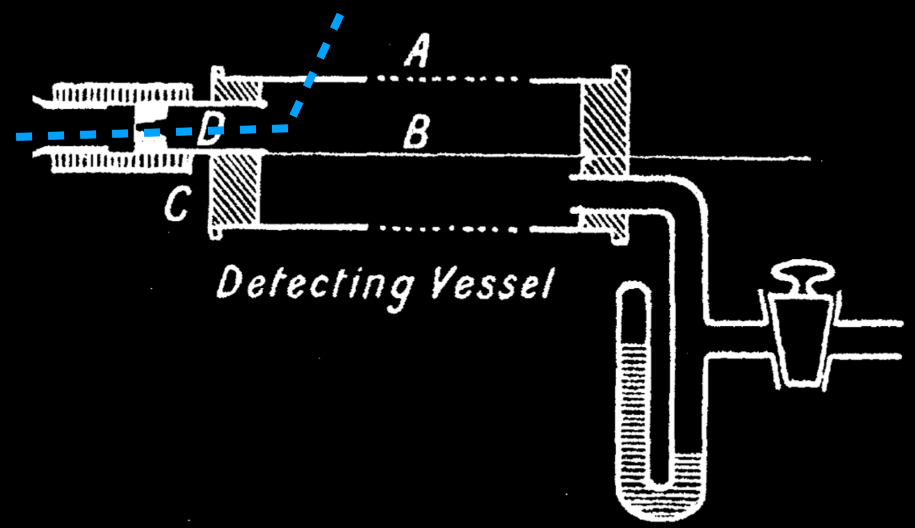


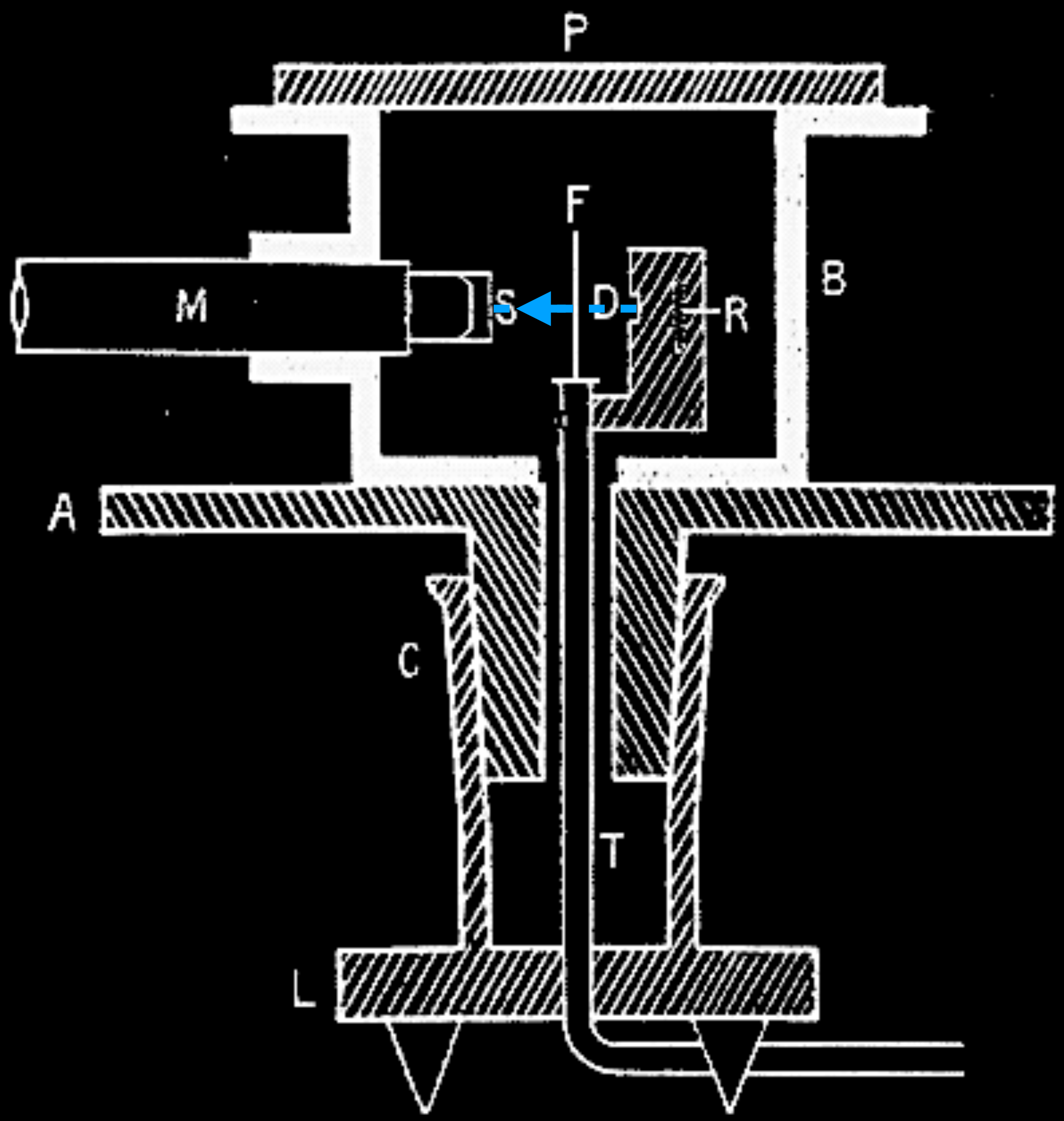


Scattering through wide angle is possible!

Anomalous scattering?

1913





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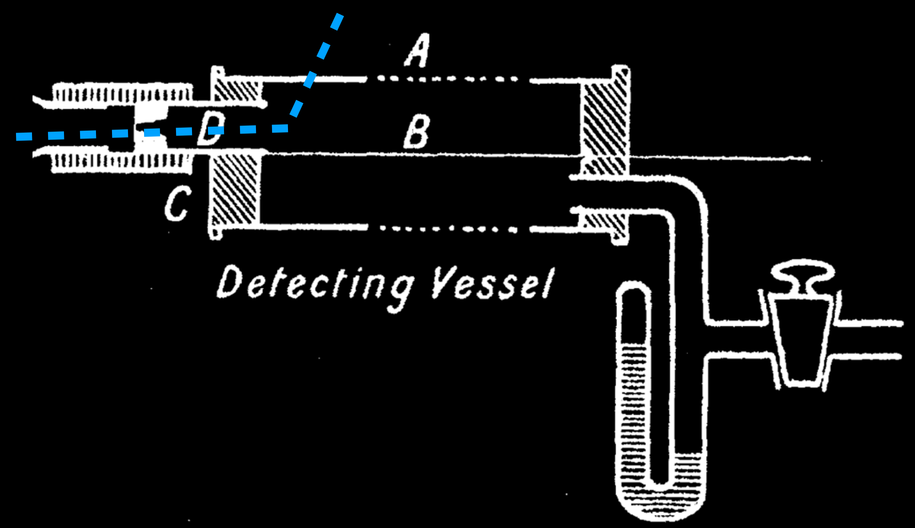
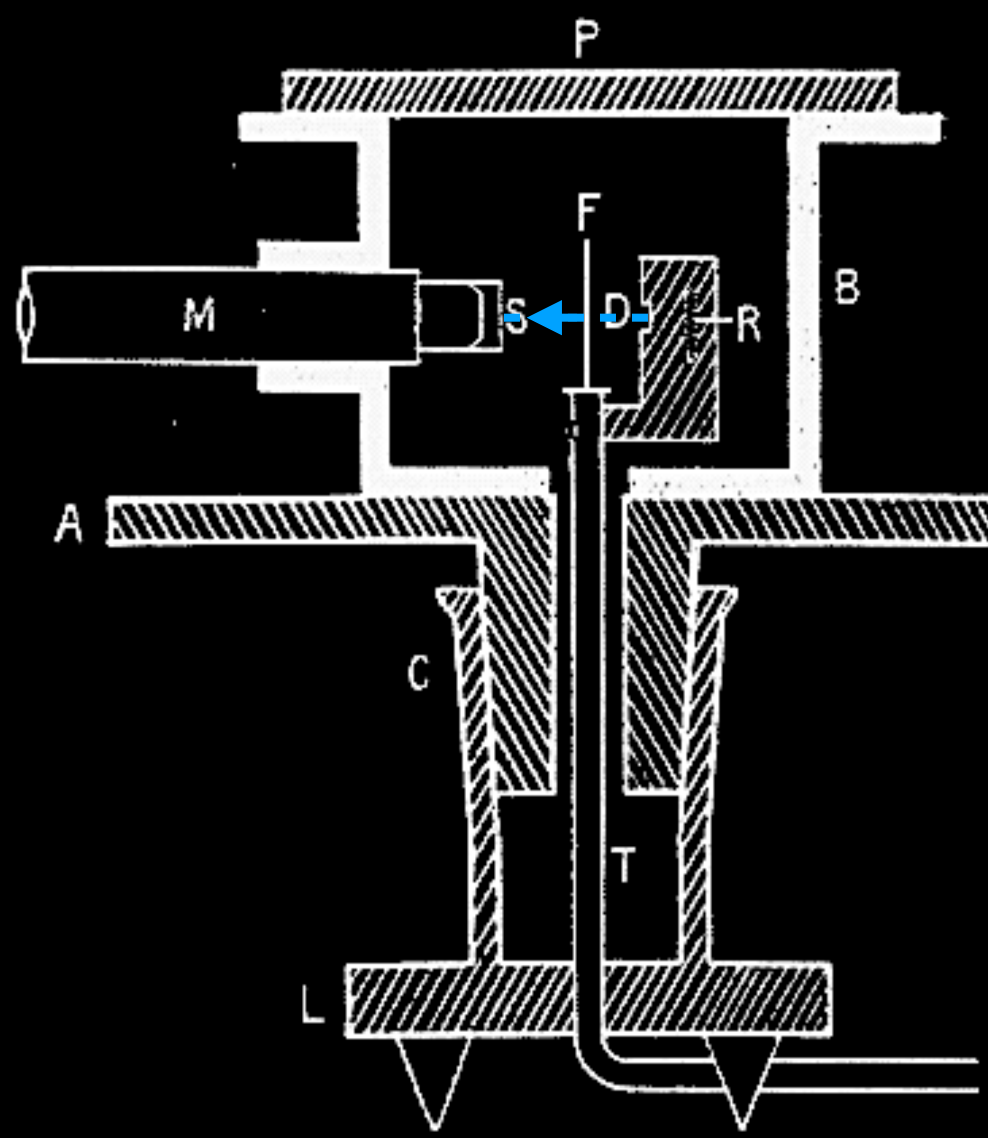
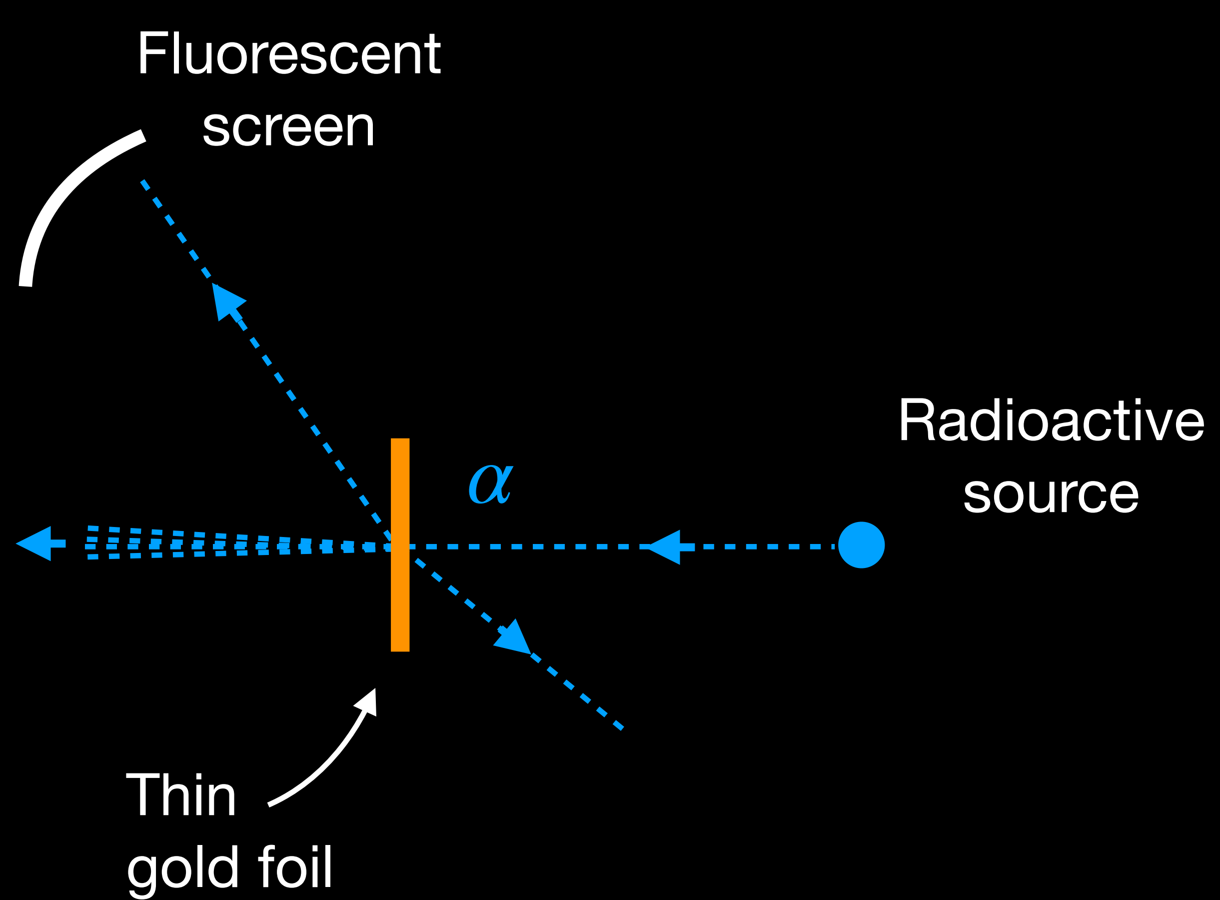
1913







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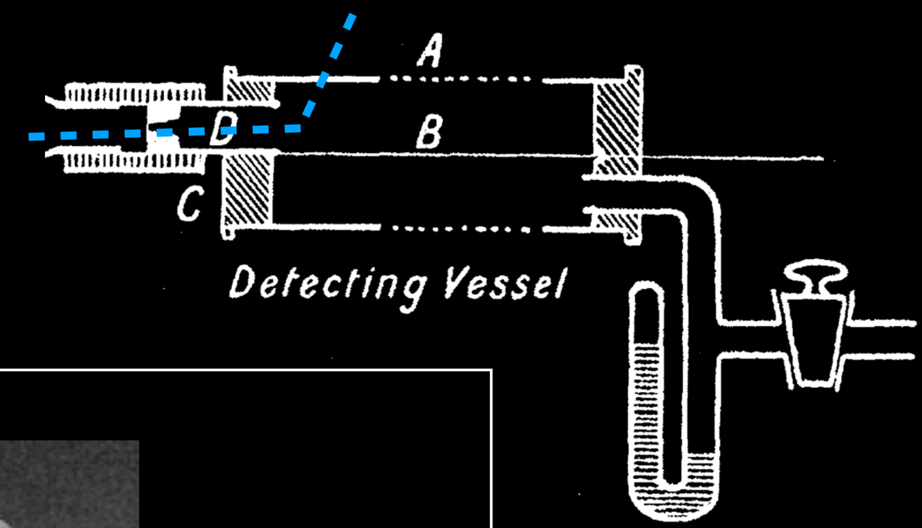
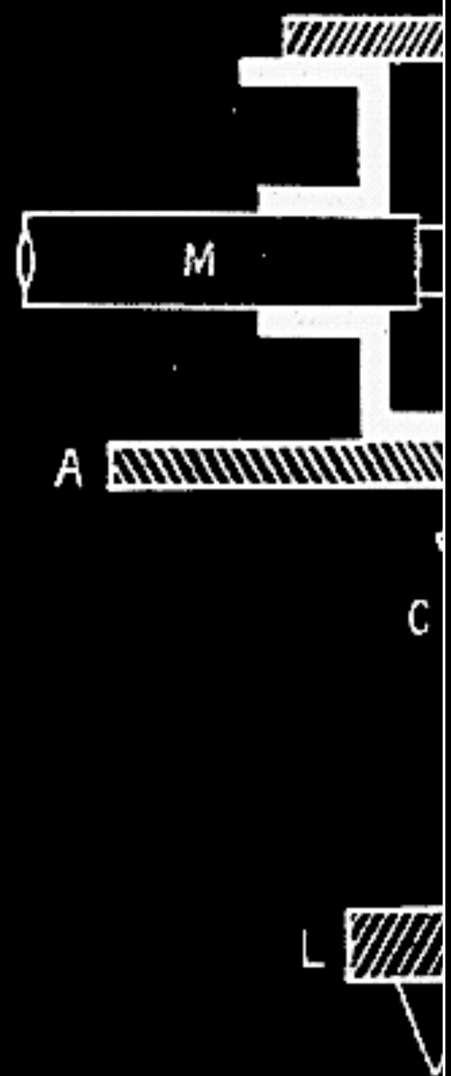
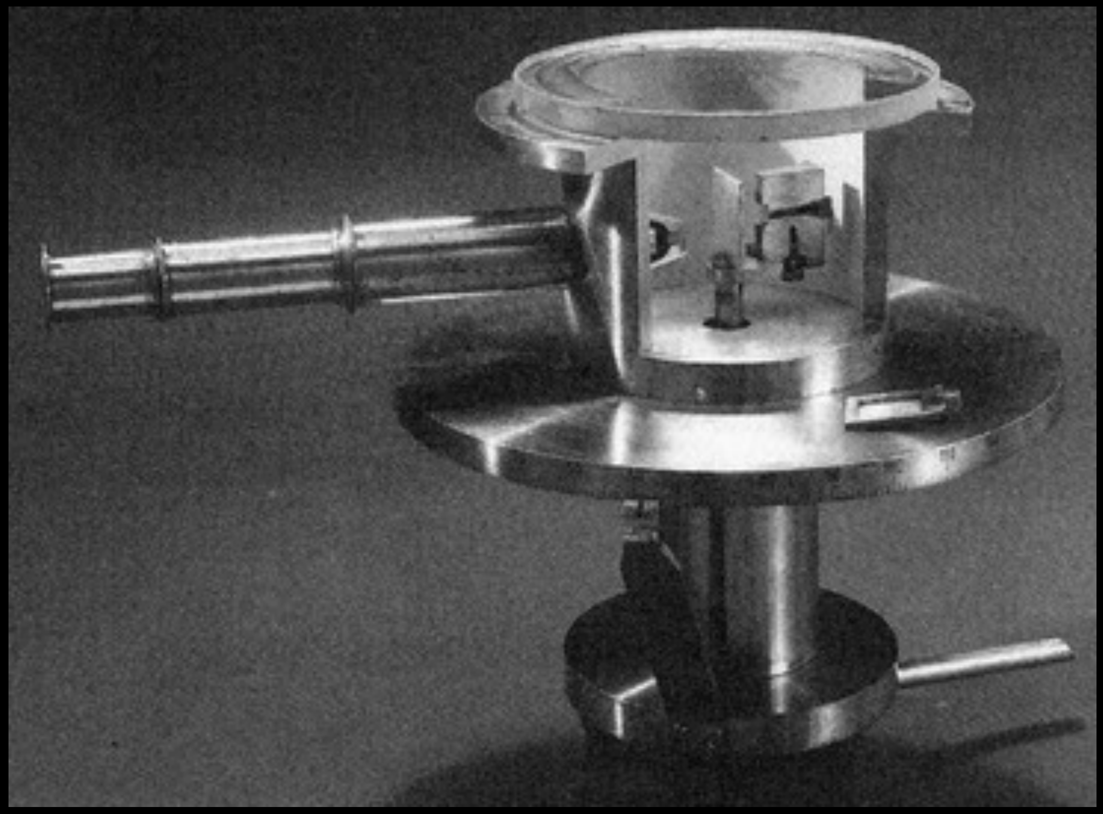






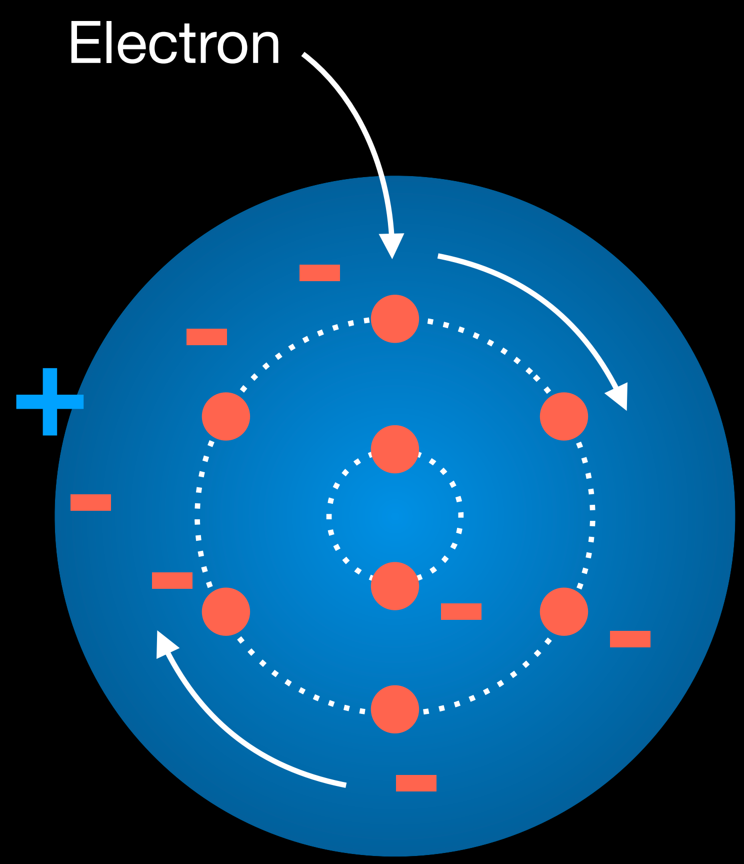
"It was quite the most incredible event that has ever happened to me in my life."

"It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

Radioactive source

The atom has a nucleus!

The atom has a nucleus!



J.J. Thomson's
"Plum pudding model"

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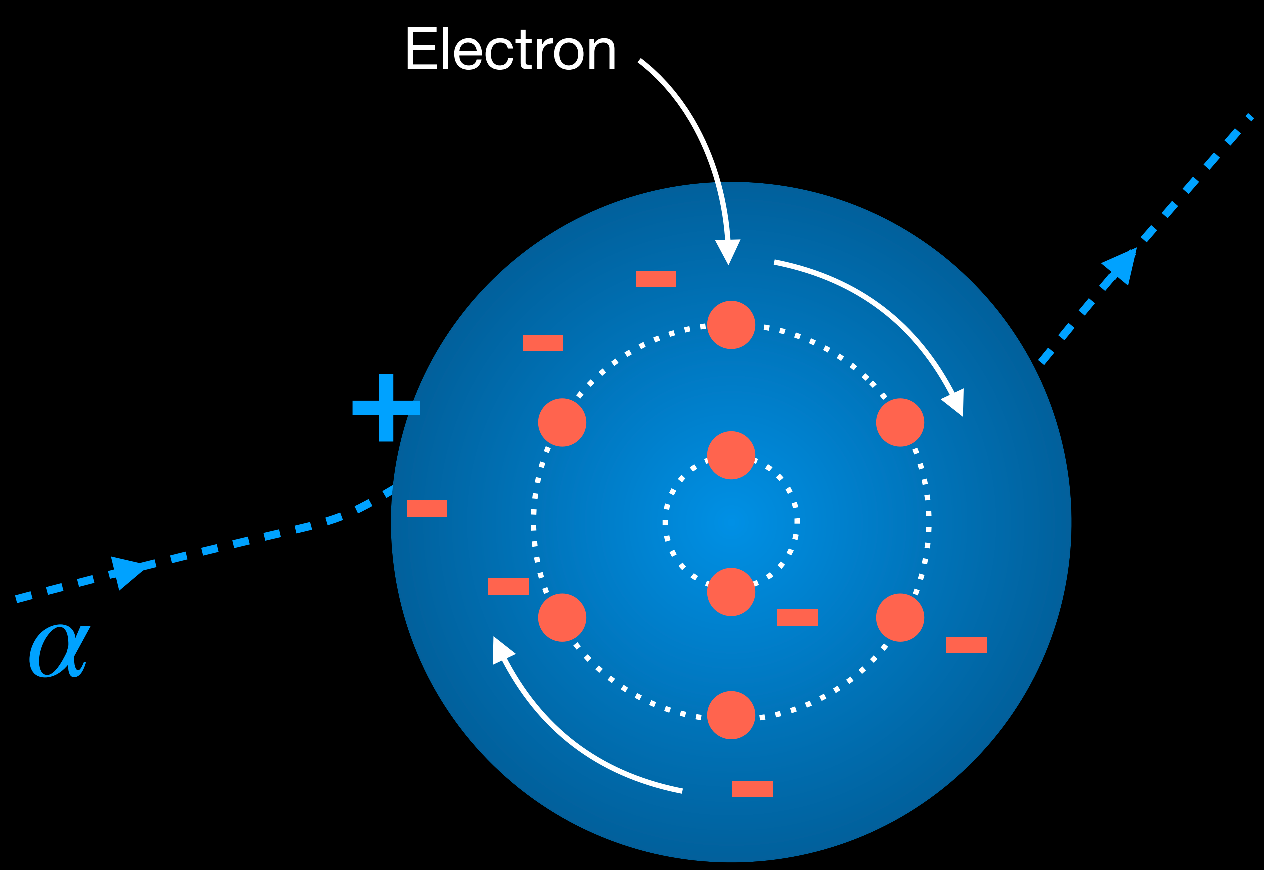

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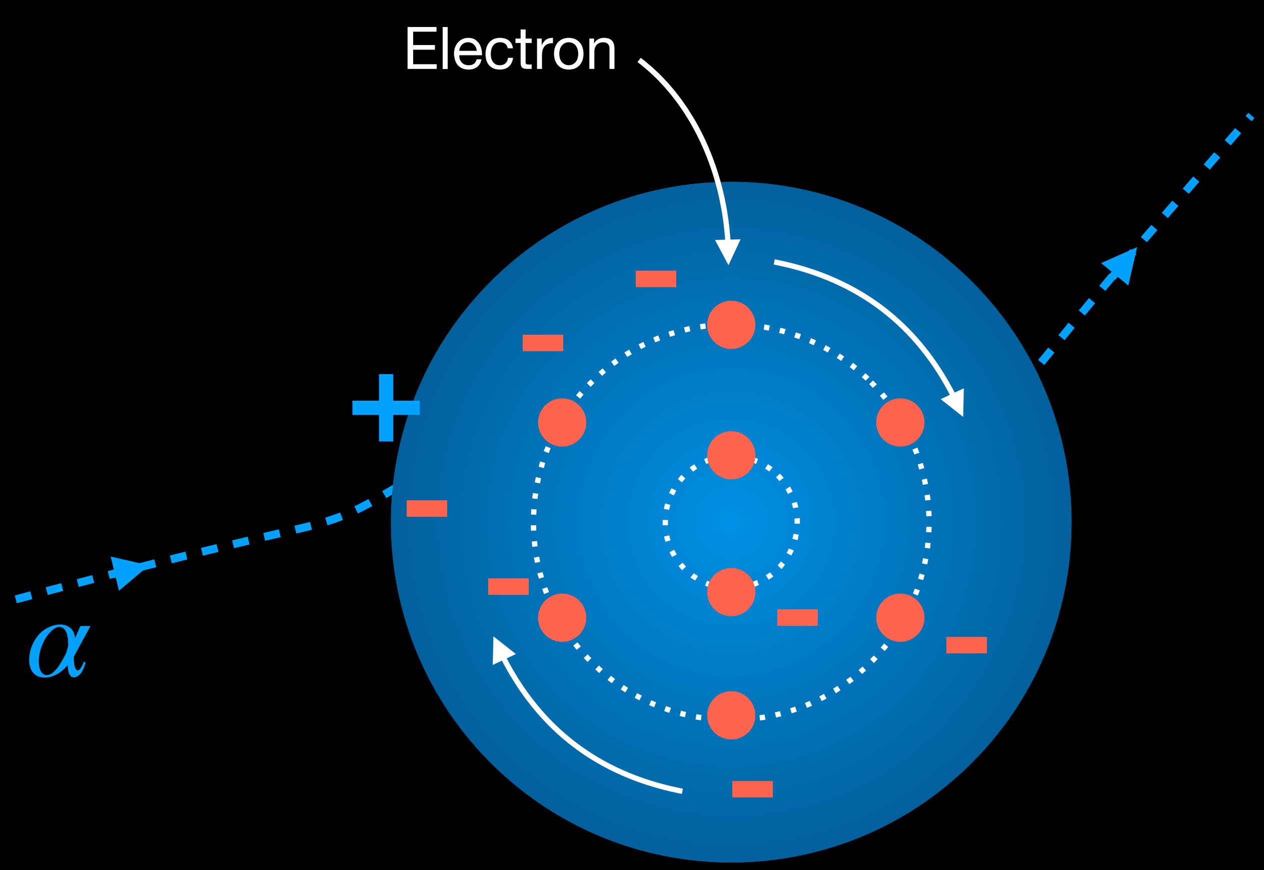

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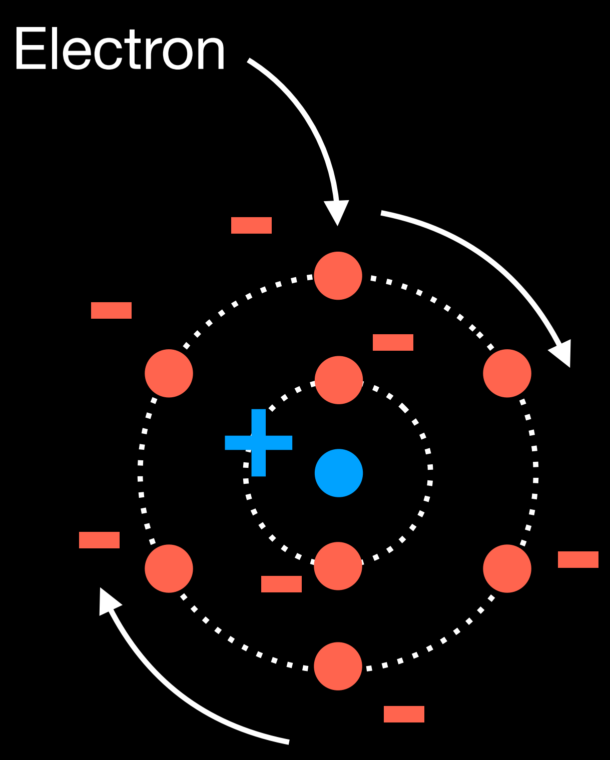

Rutherford's
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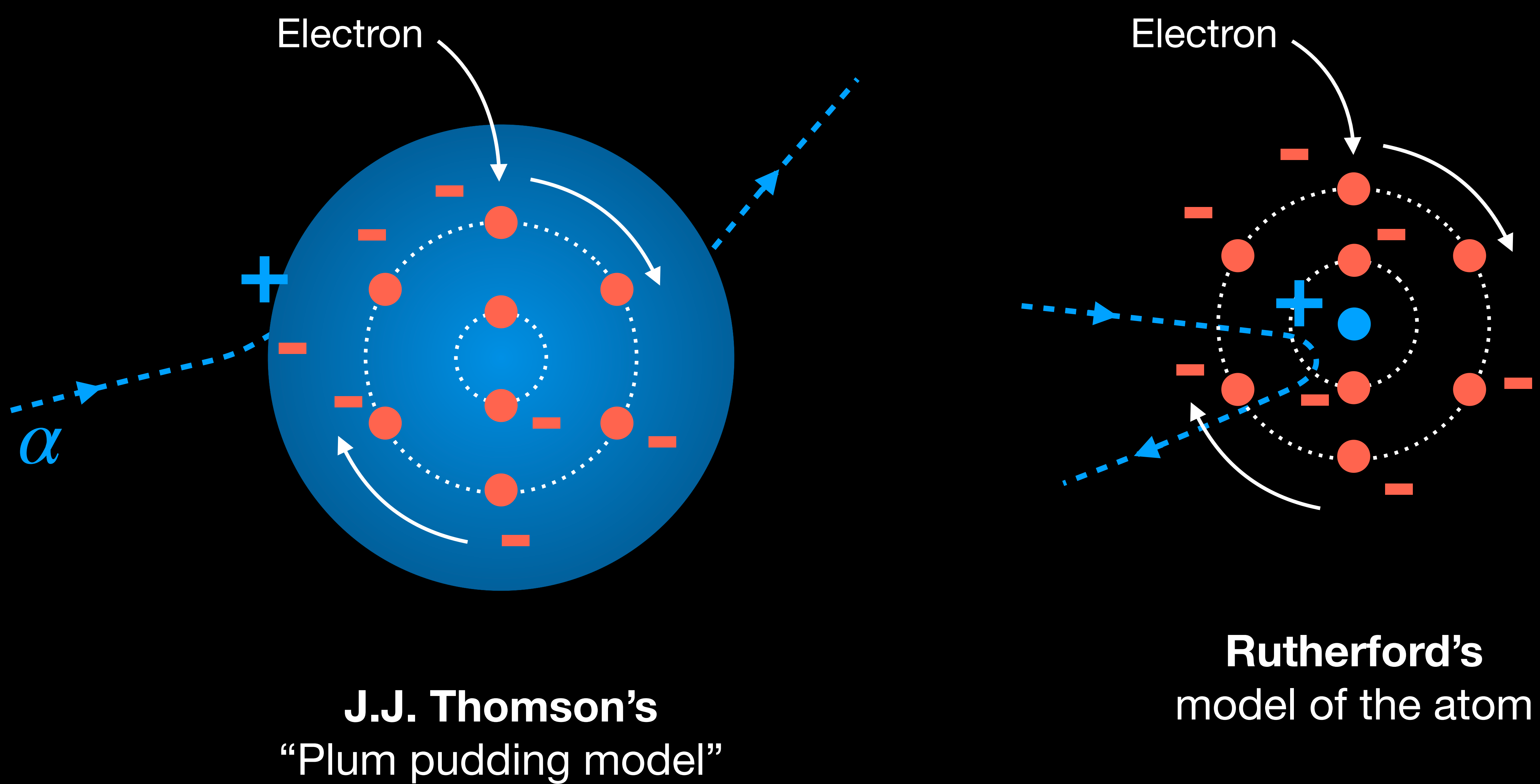

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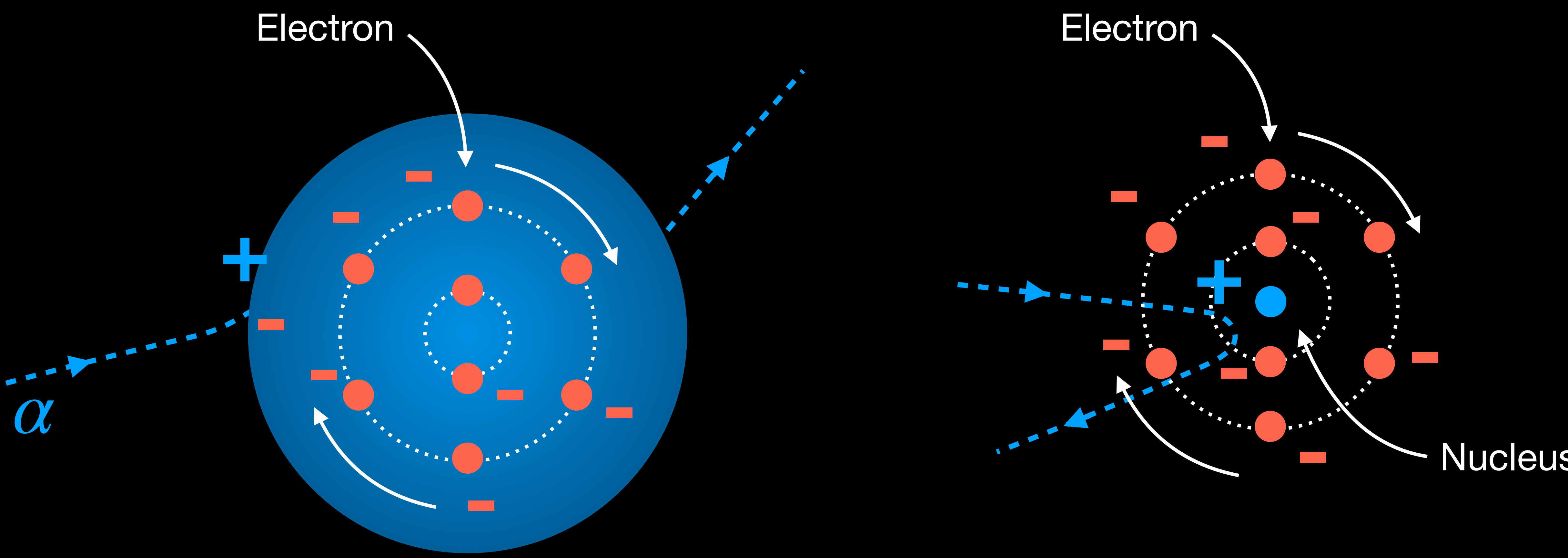

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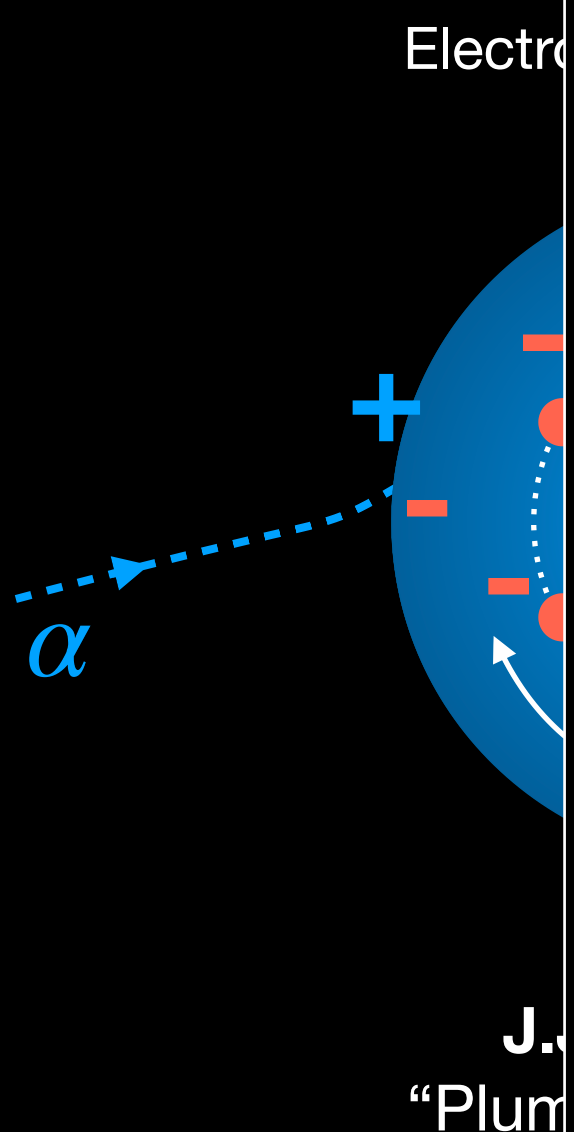
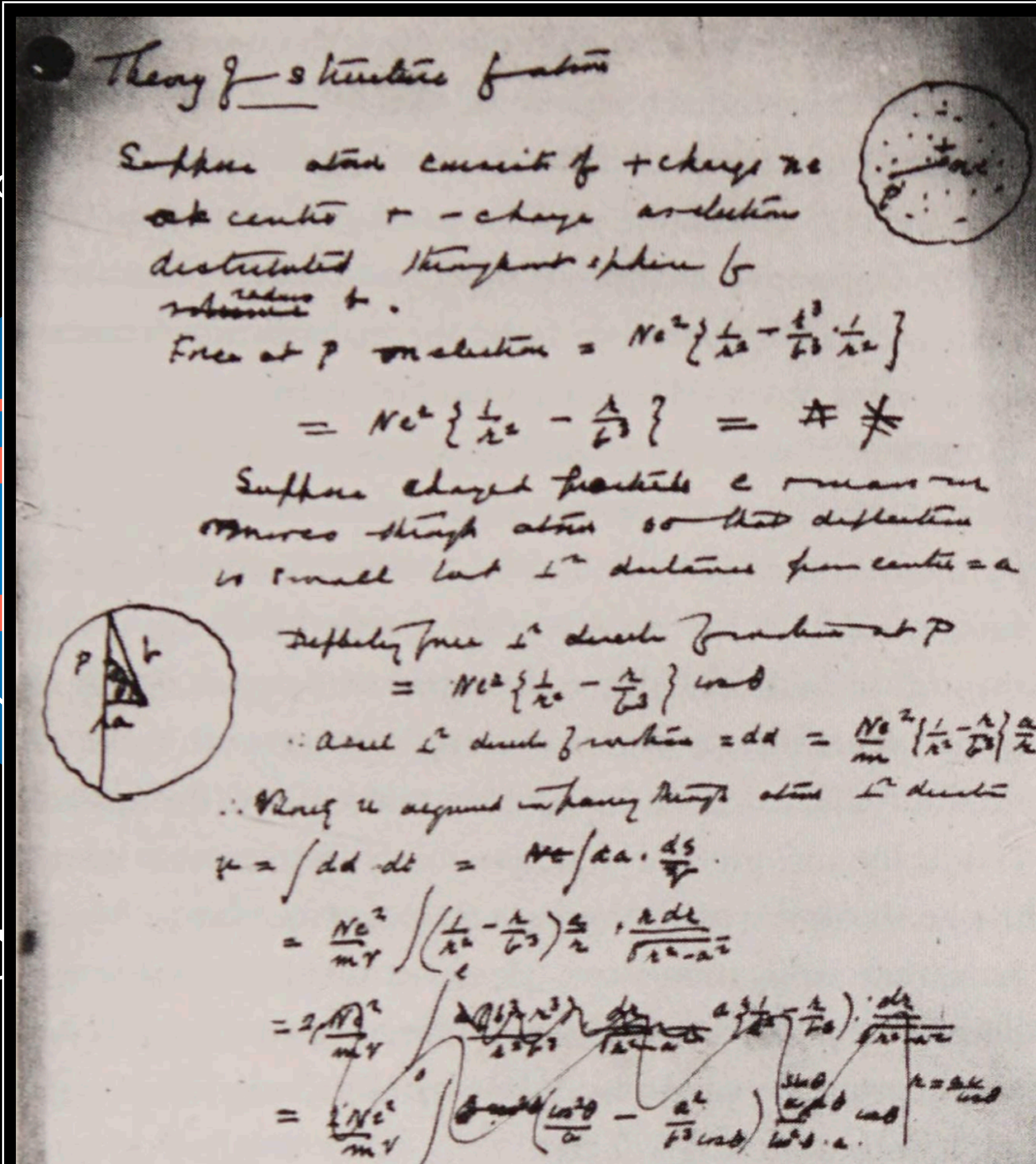
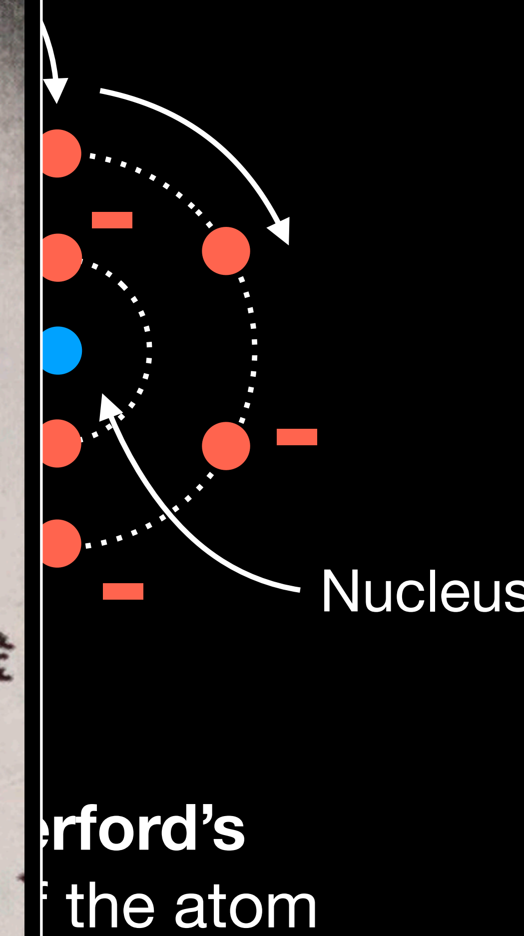




Rutherford’s calculations describing the scattering



1914: WW1 interrupts science

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invests Nobel prize money in war bonds, organizes a mobile X-ray service along the front

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Rutherford and Thomson:
Serve on the Admiralty physics board

What is the nucleus made of?

Rutherford: “α particles can collide with the nucleus of a hydrogen atom”

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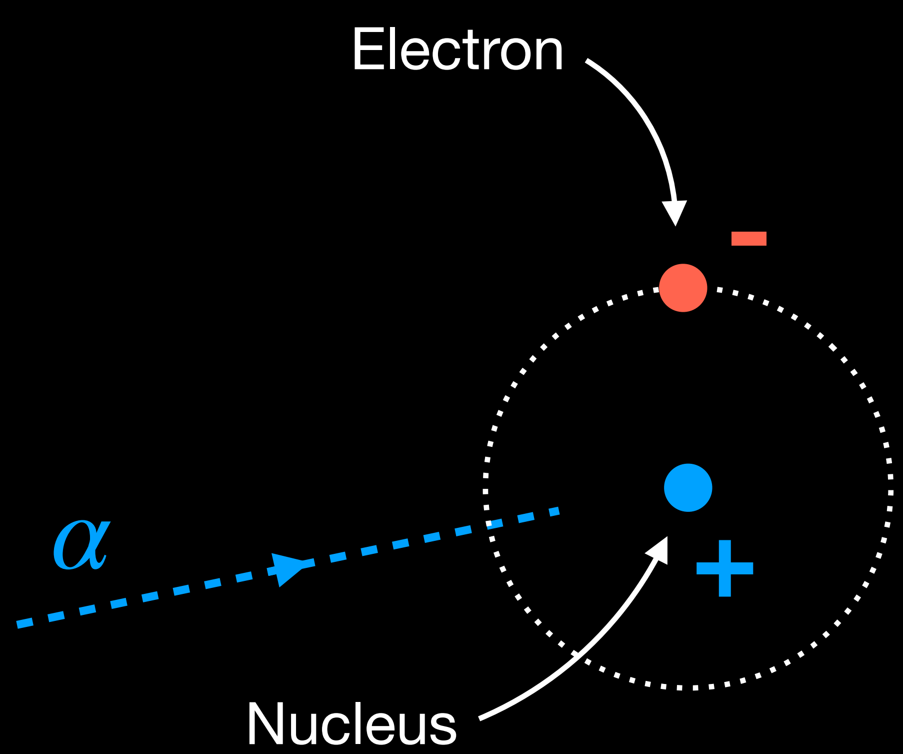

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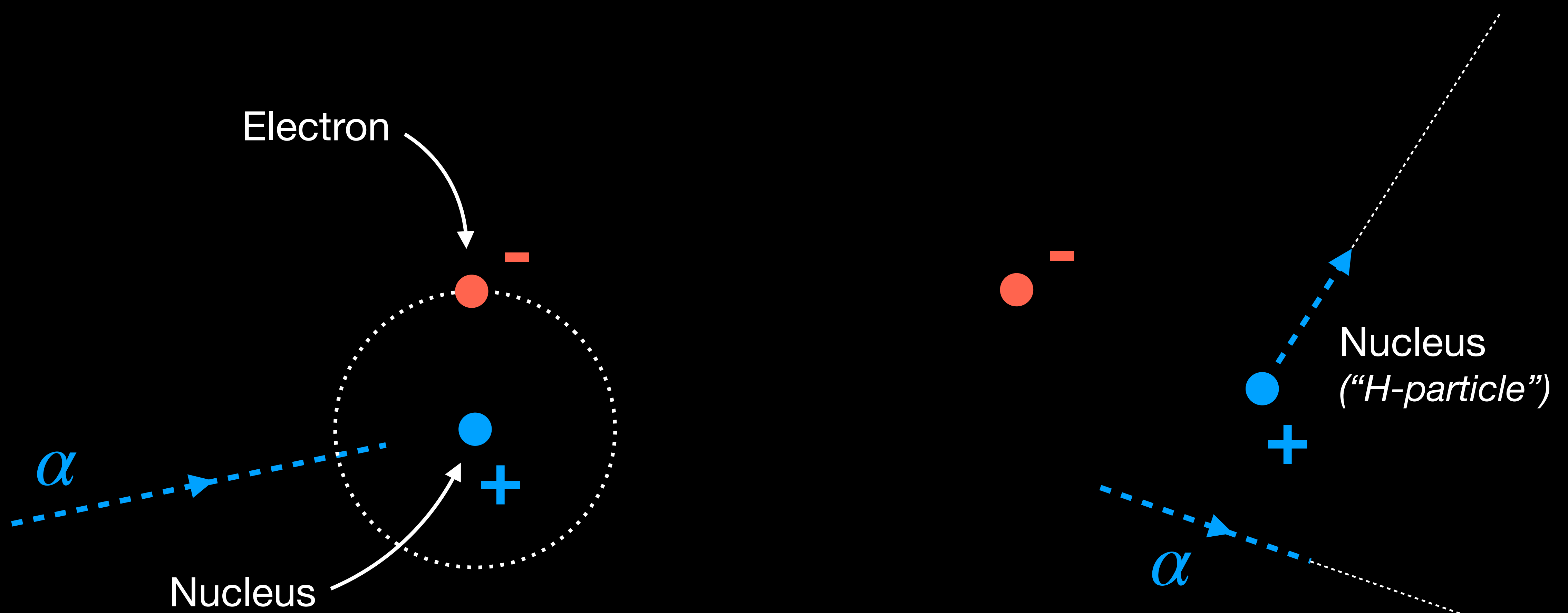

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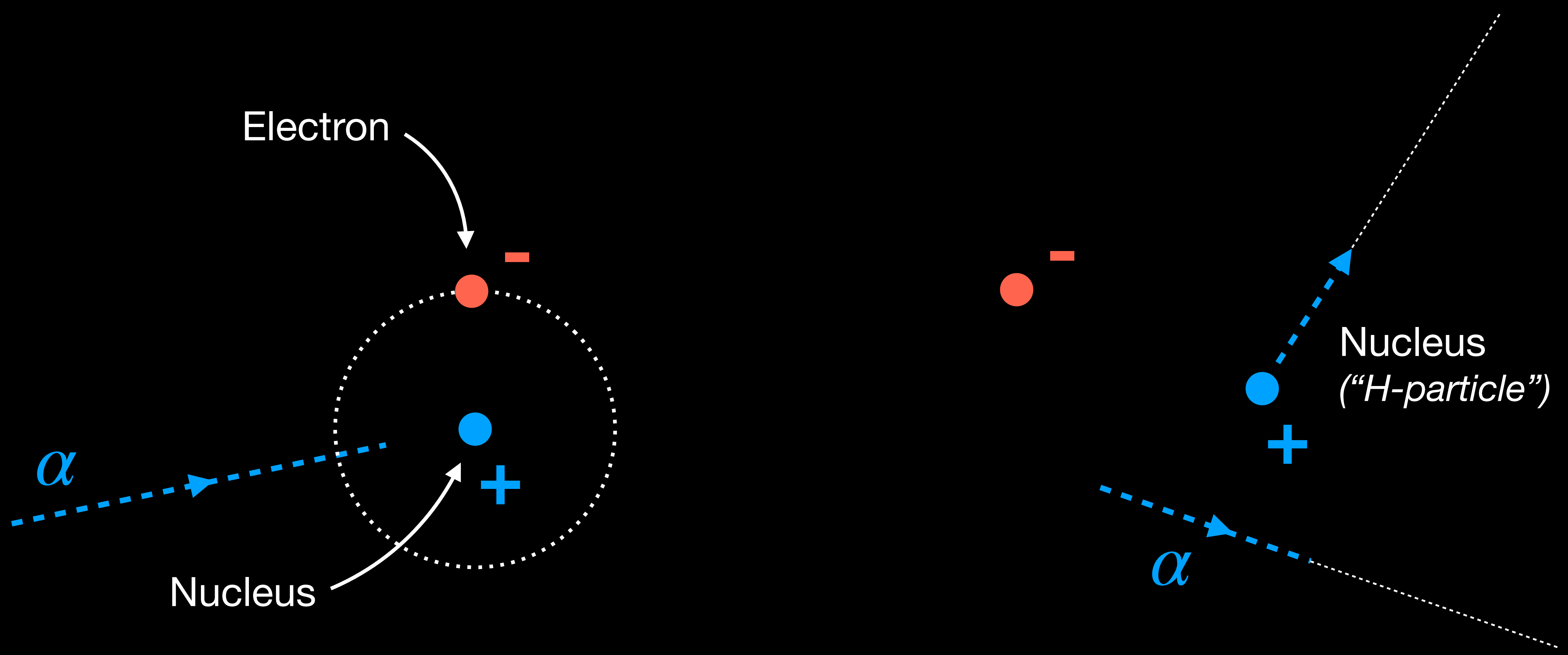
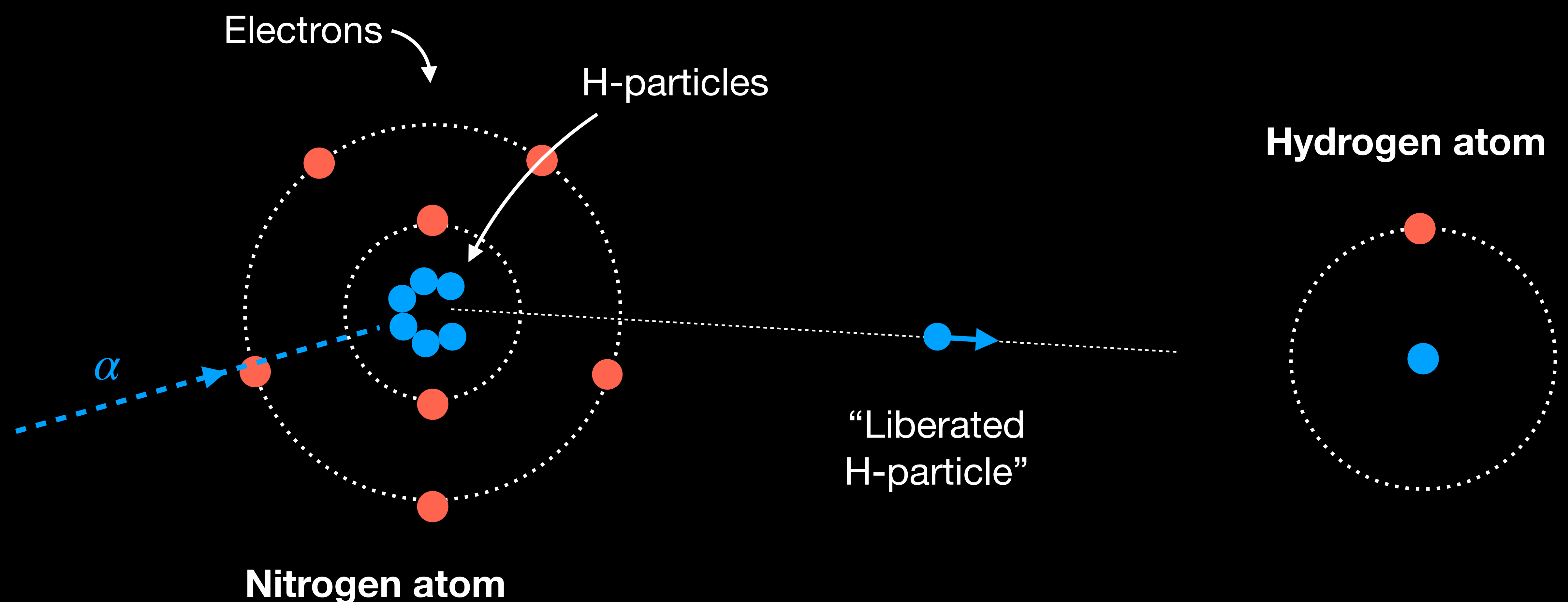


"In an end-on collision, the H-particle will have about four times the range of the α-particle producing it."

Hydrogen contained in nitrogen?

April 1919



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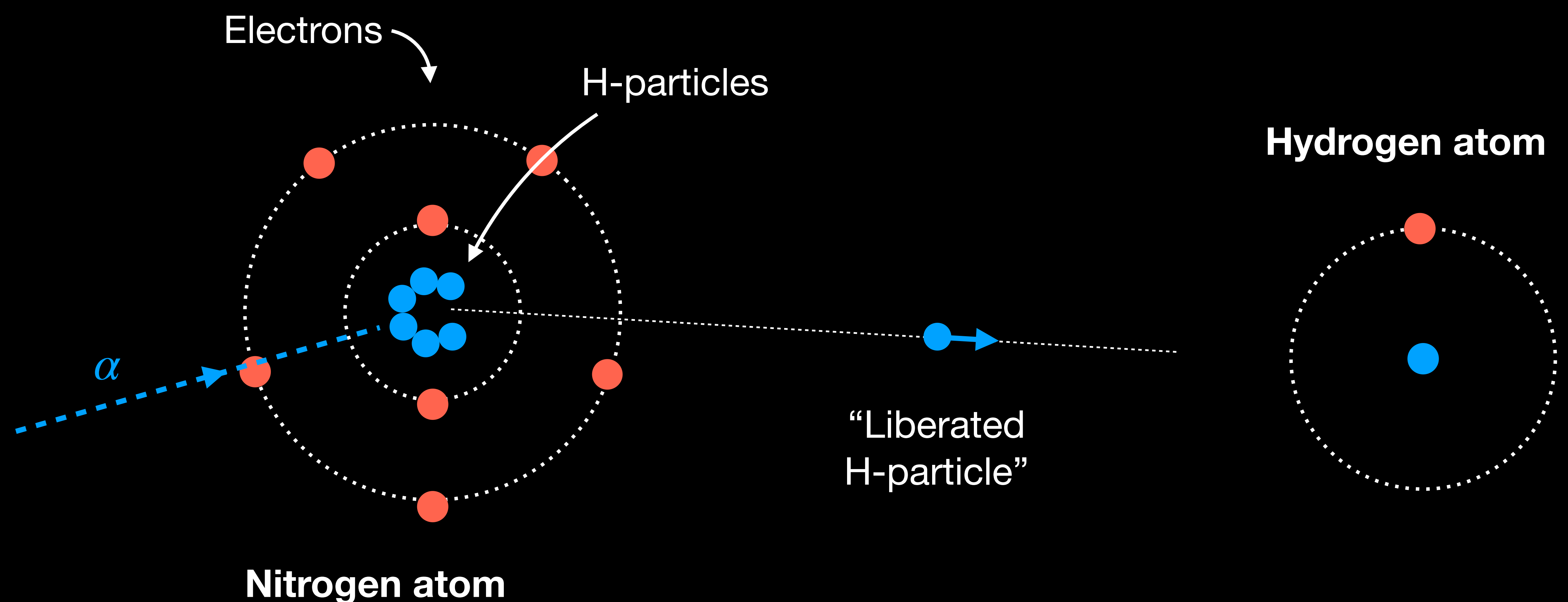
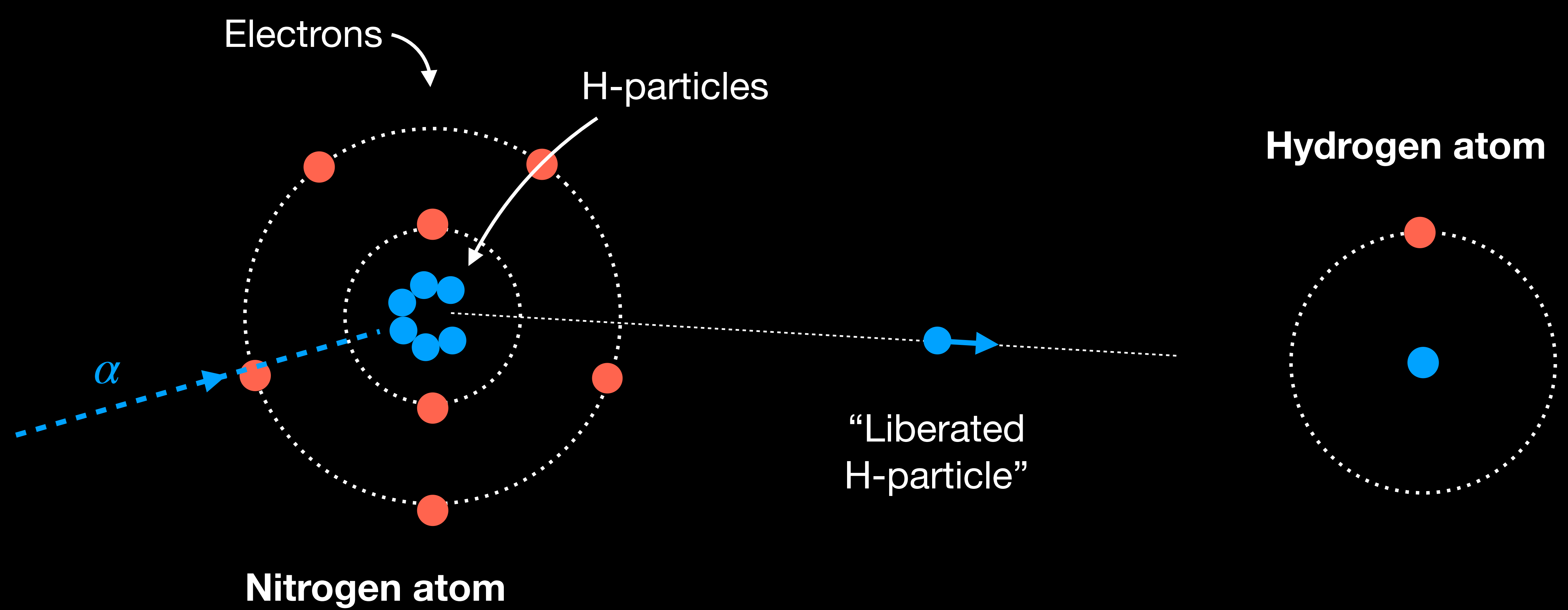


"We must conclude that the hydrogen atom which is liberated formed a constituent part of the nitrogen nucleus."

Hydrogen contained in nitrogen?

April 1919

"Considering the enormous intensity of the forces brought into play, it is not so much a matter of surprise that the nitrogen atom should suffer disintegration."



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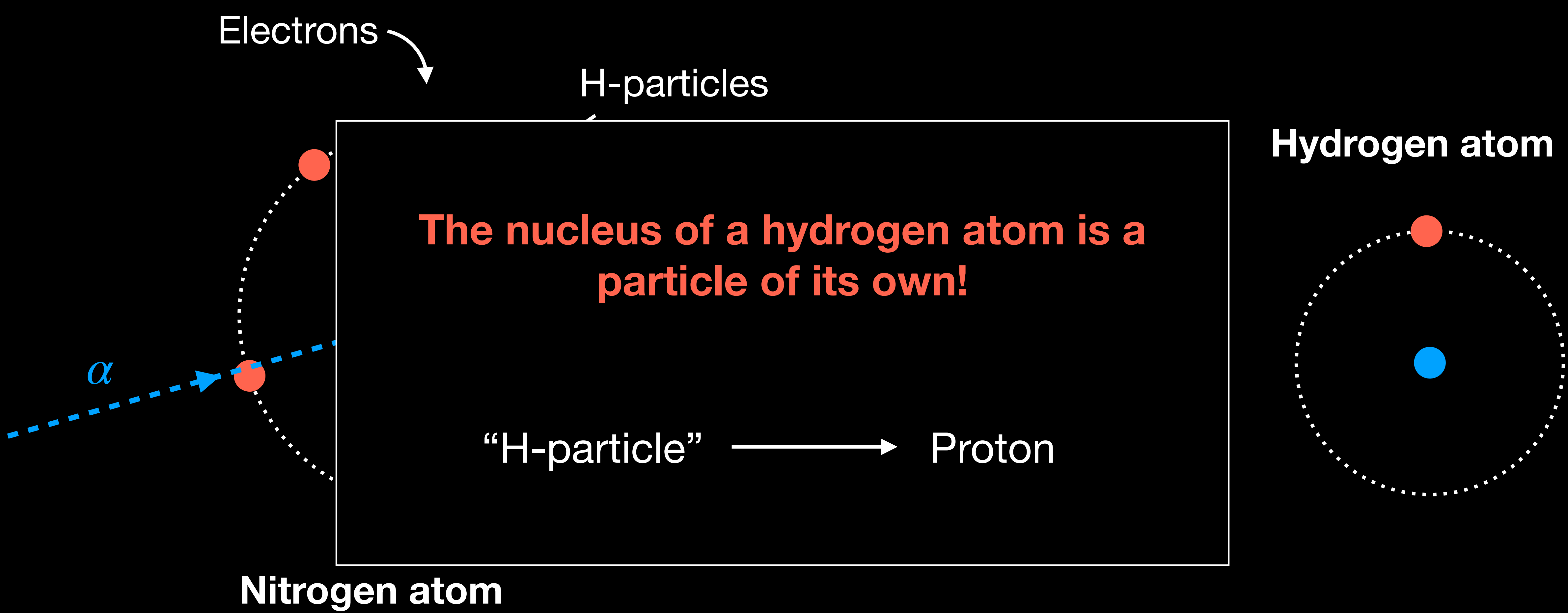

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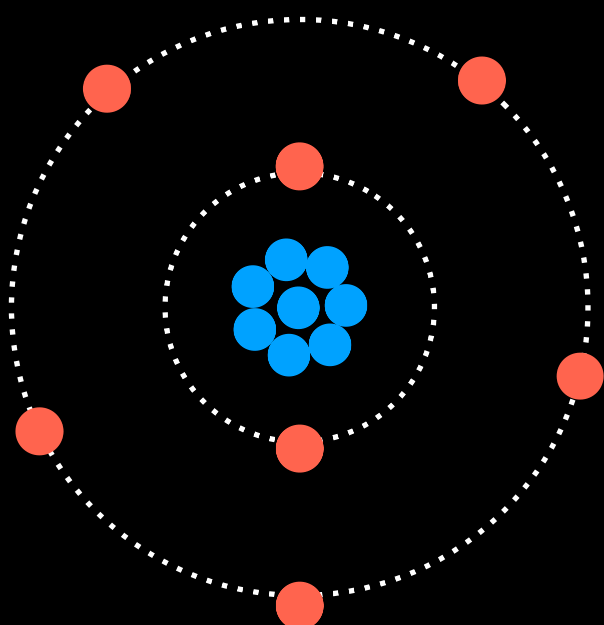
“Nuclear chemistry”

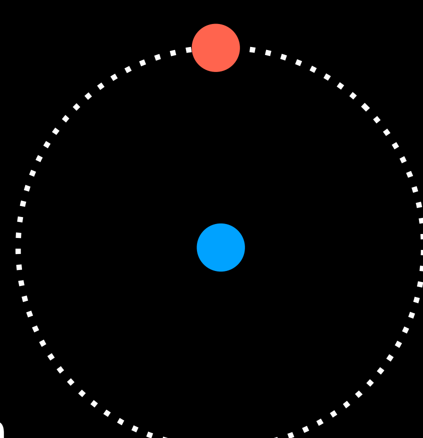
Proton

Electron

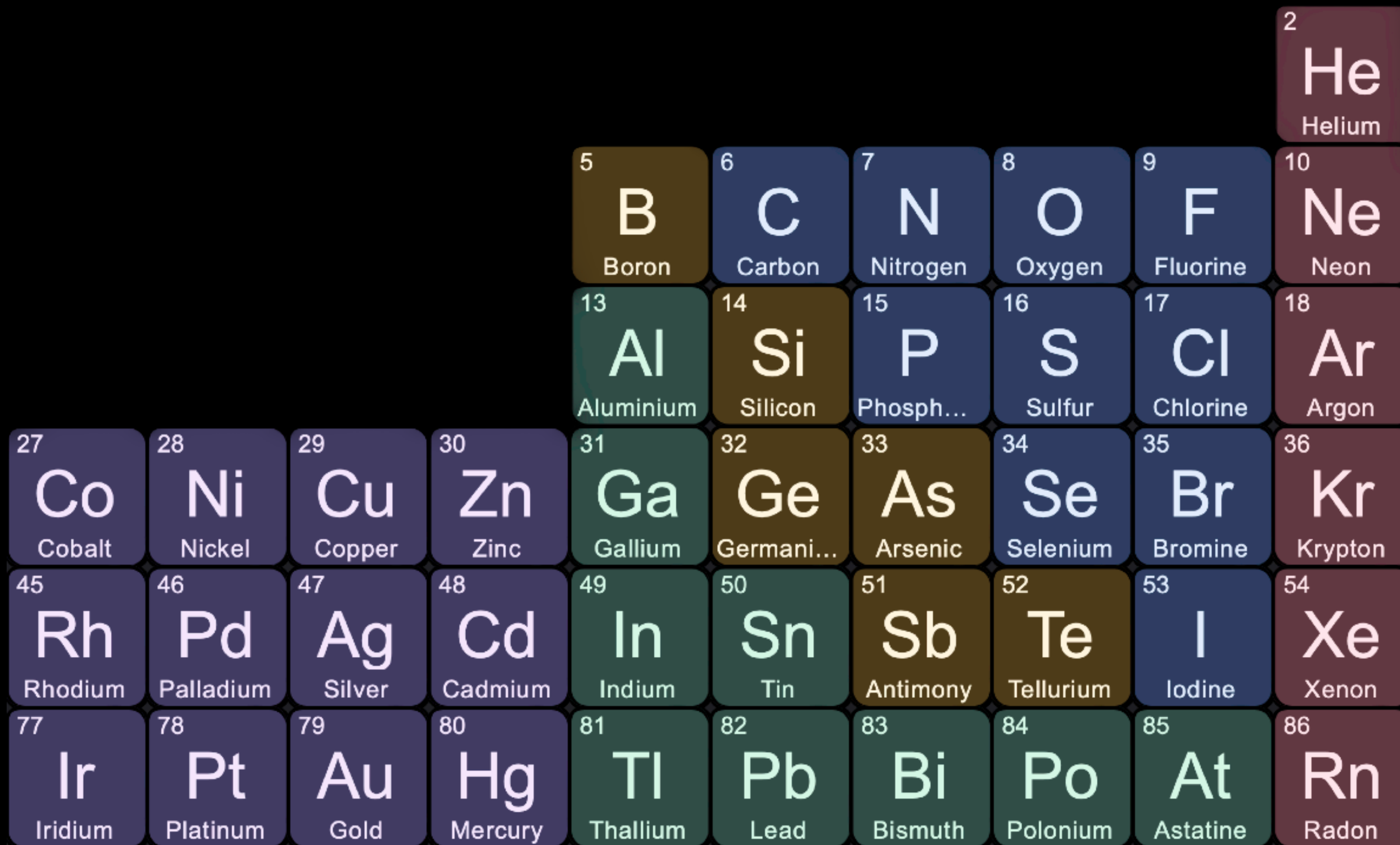
Atoms are not “elementary”, they have their own building blocks!



Nitrogen
(Heavier than hydrogen)



Hydrogen



Adding more and more electrons *(and protons)* builds up the elements in the periodic table

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Electron

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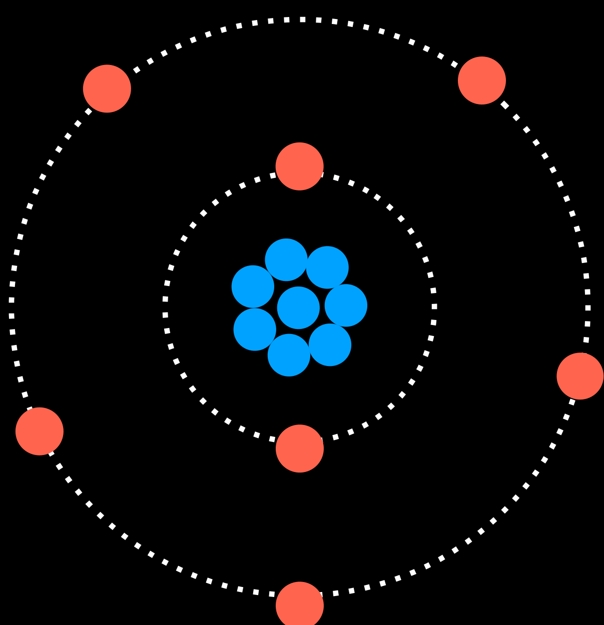
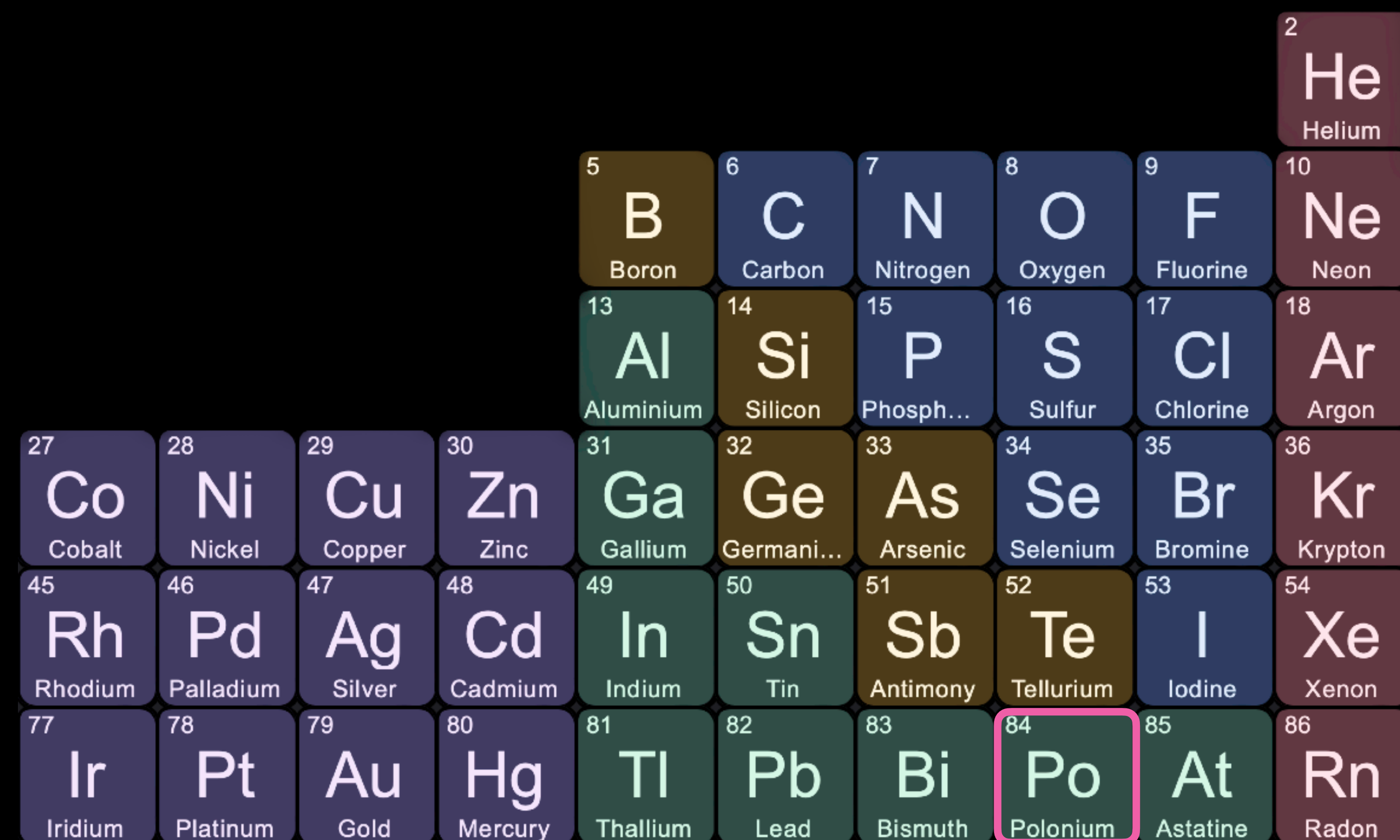
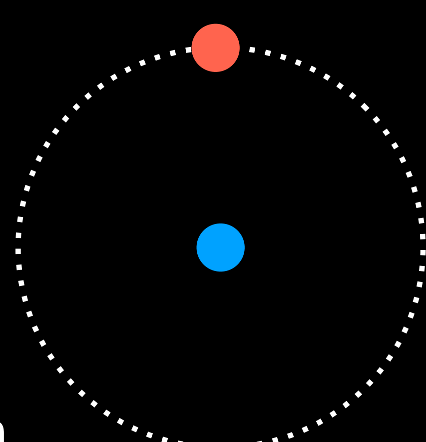


Nitrogen
(Heavier than hydrogen)





Hydrogen

Adding more and more electrons *(and protons)* builds up the elements in the periodic table

“Nuclear chemistry”

Proton

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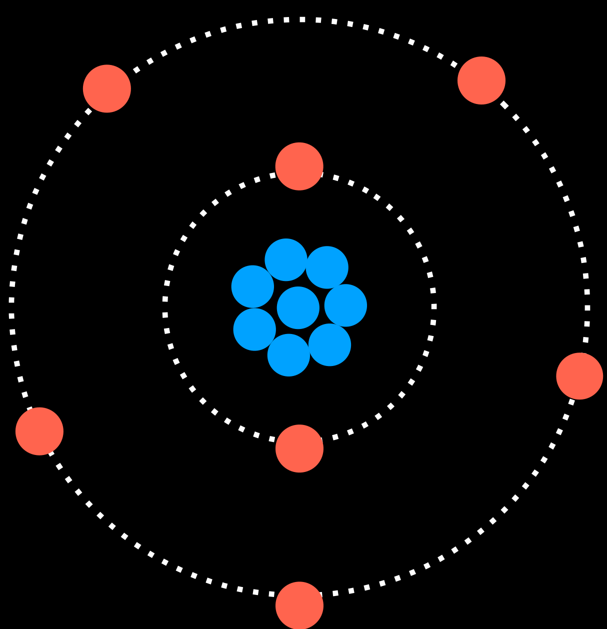

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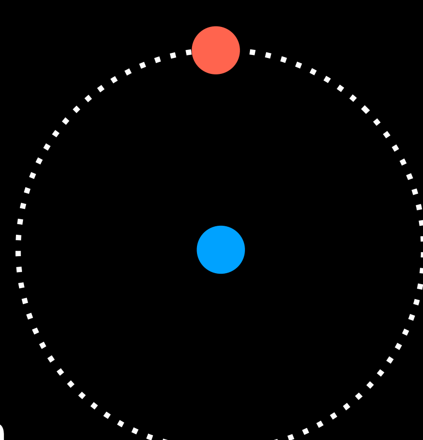

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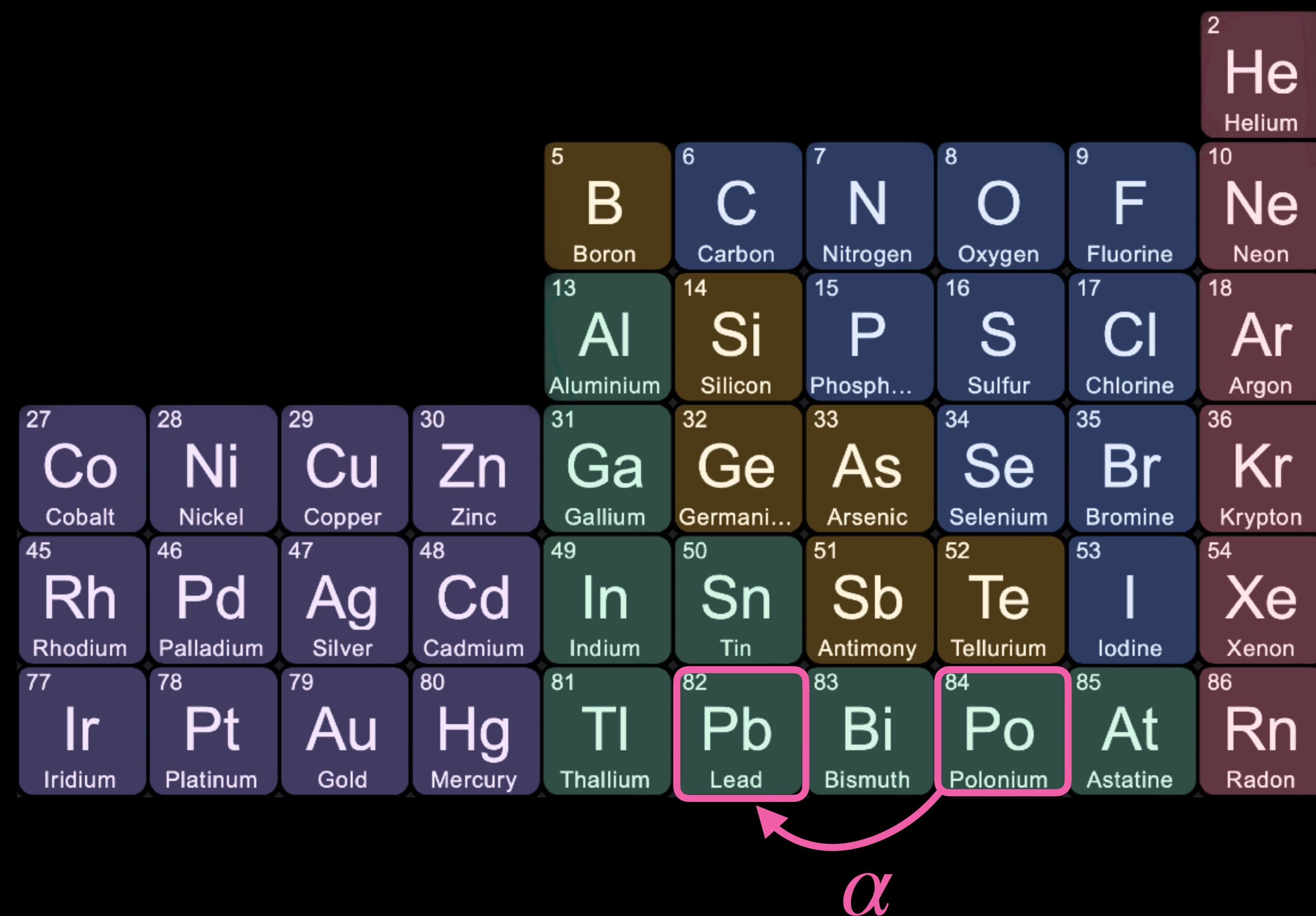

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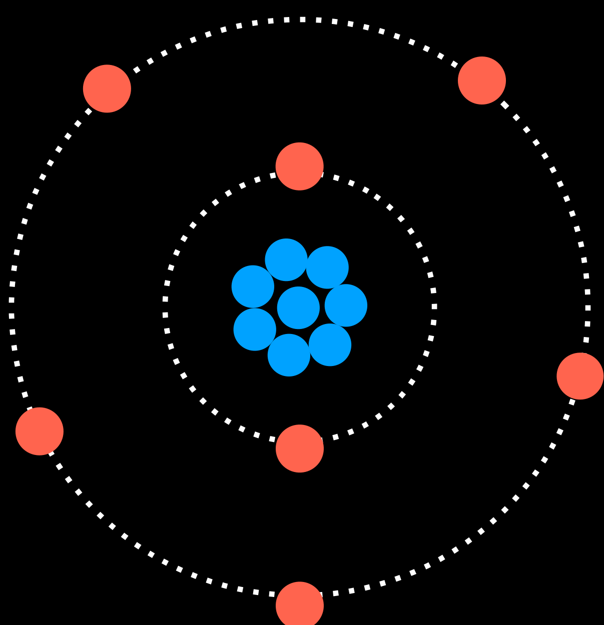

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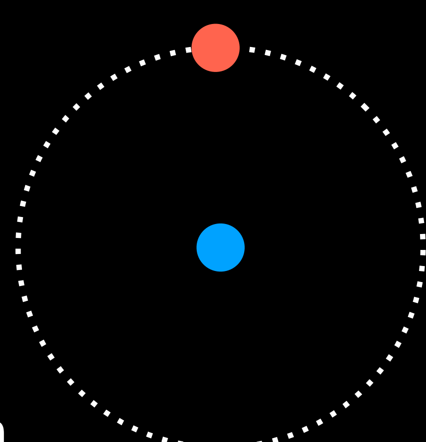

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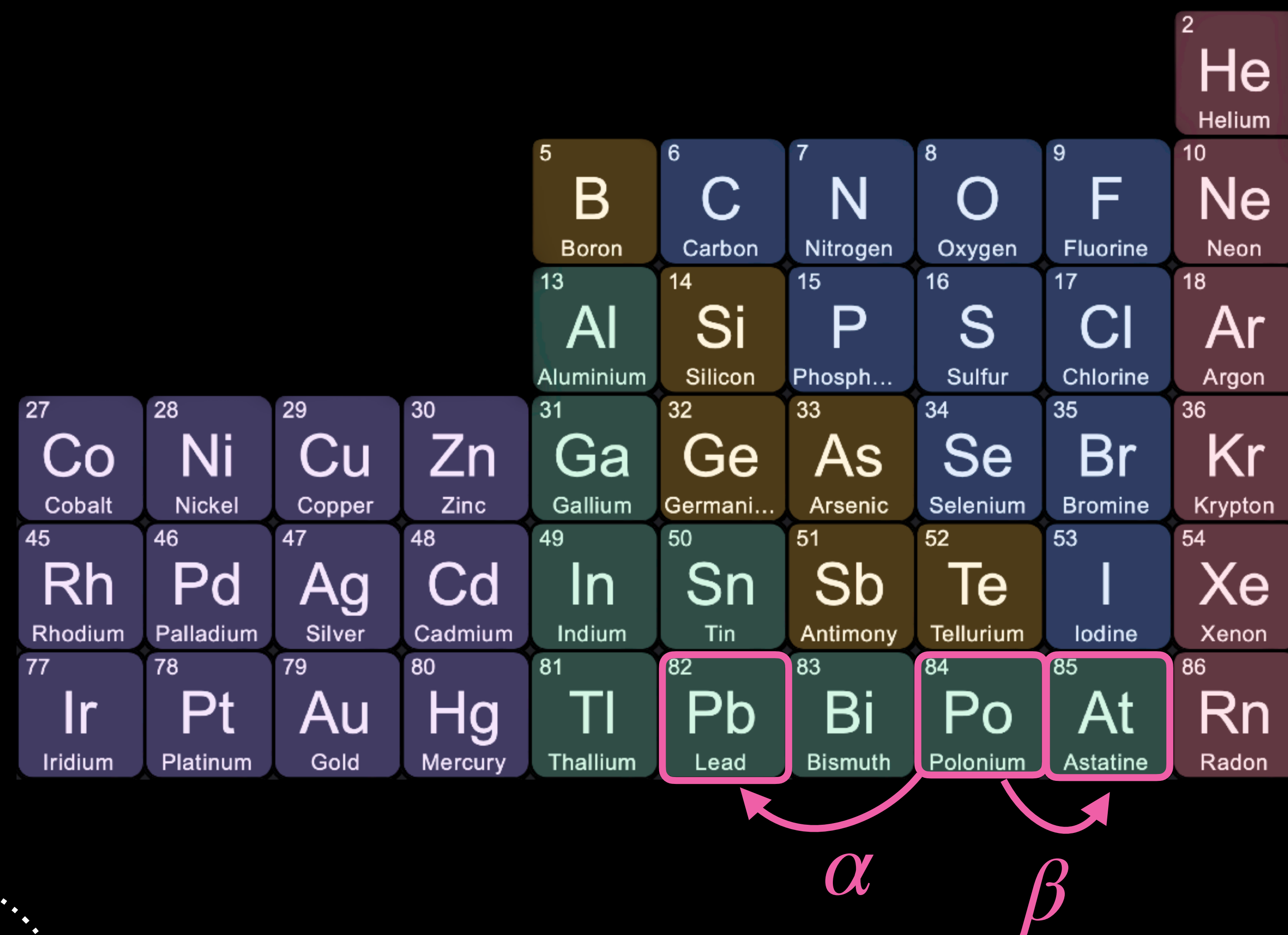

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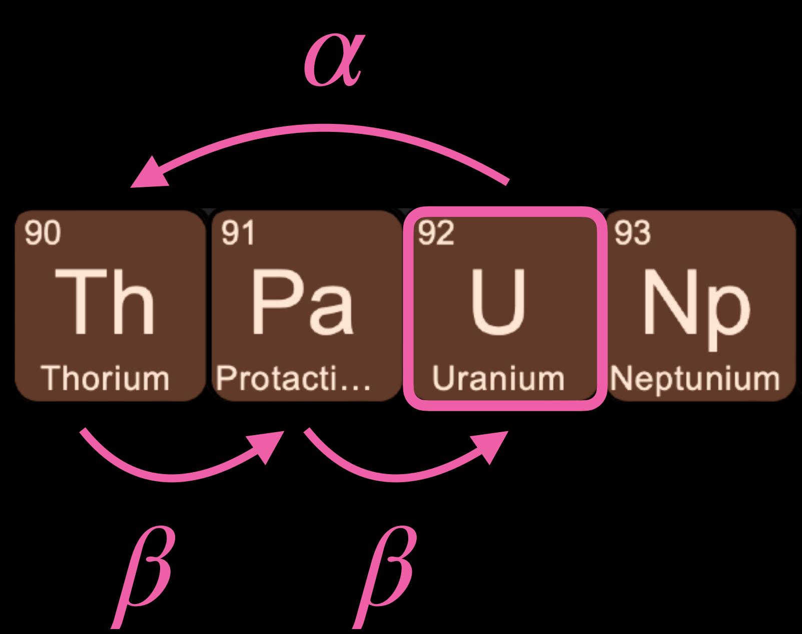
Another hint from chemistry

Can chemical elements exist “multiple times”?



Uranium

↓ α

Thorium

↓ β

Protactinium

↓ β

Uranium

Frederick Soddy

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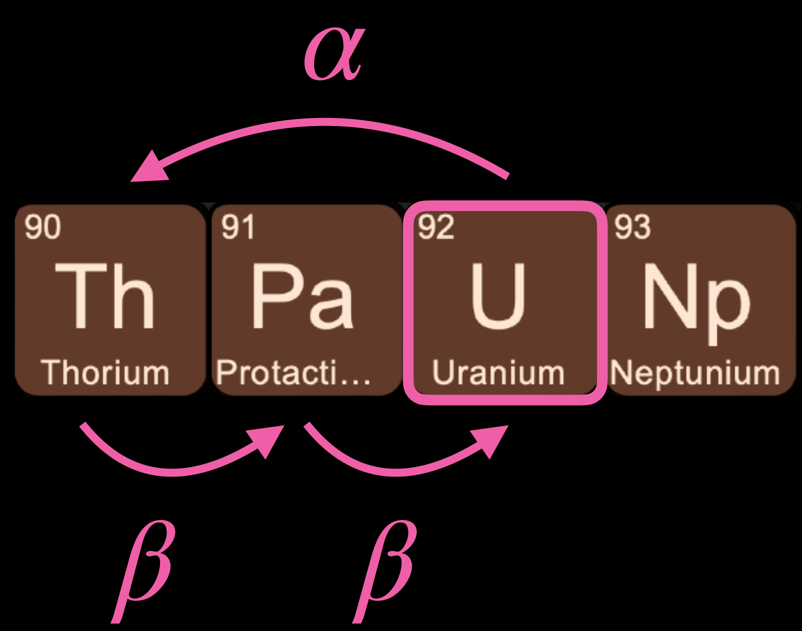

Uranium

$\downarrow \alpha$

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$\downarrow \beta$

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$\downarrow \beta$

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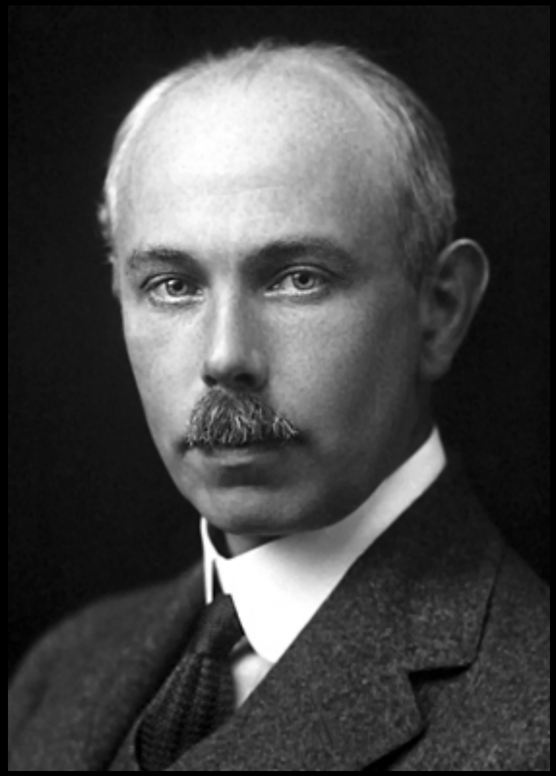

Francis Aston

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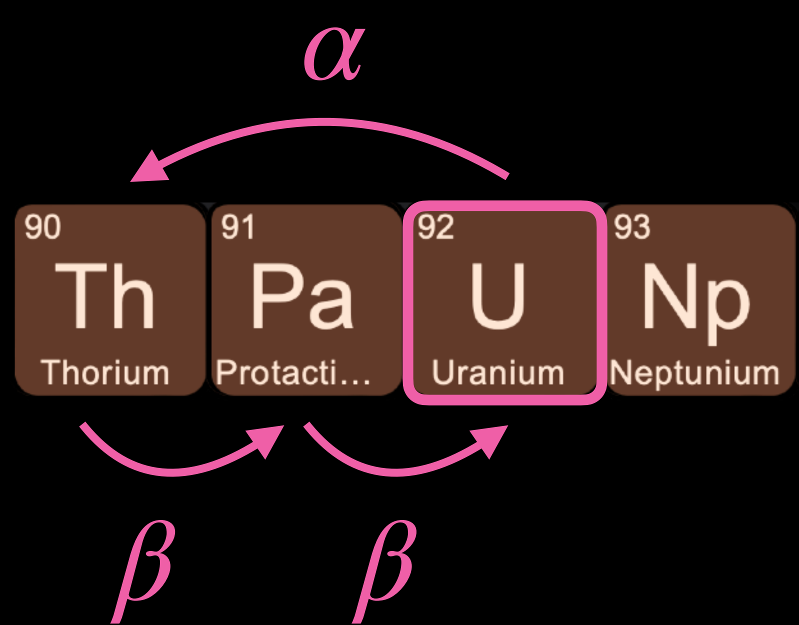

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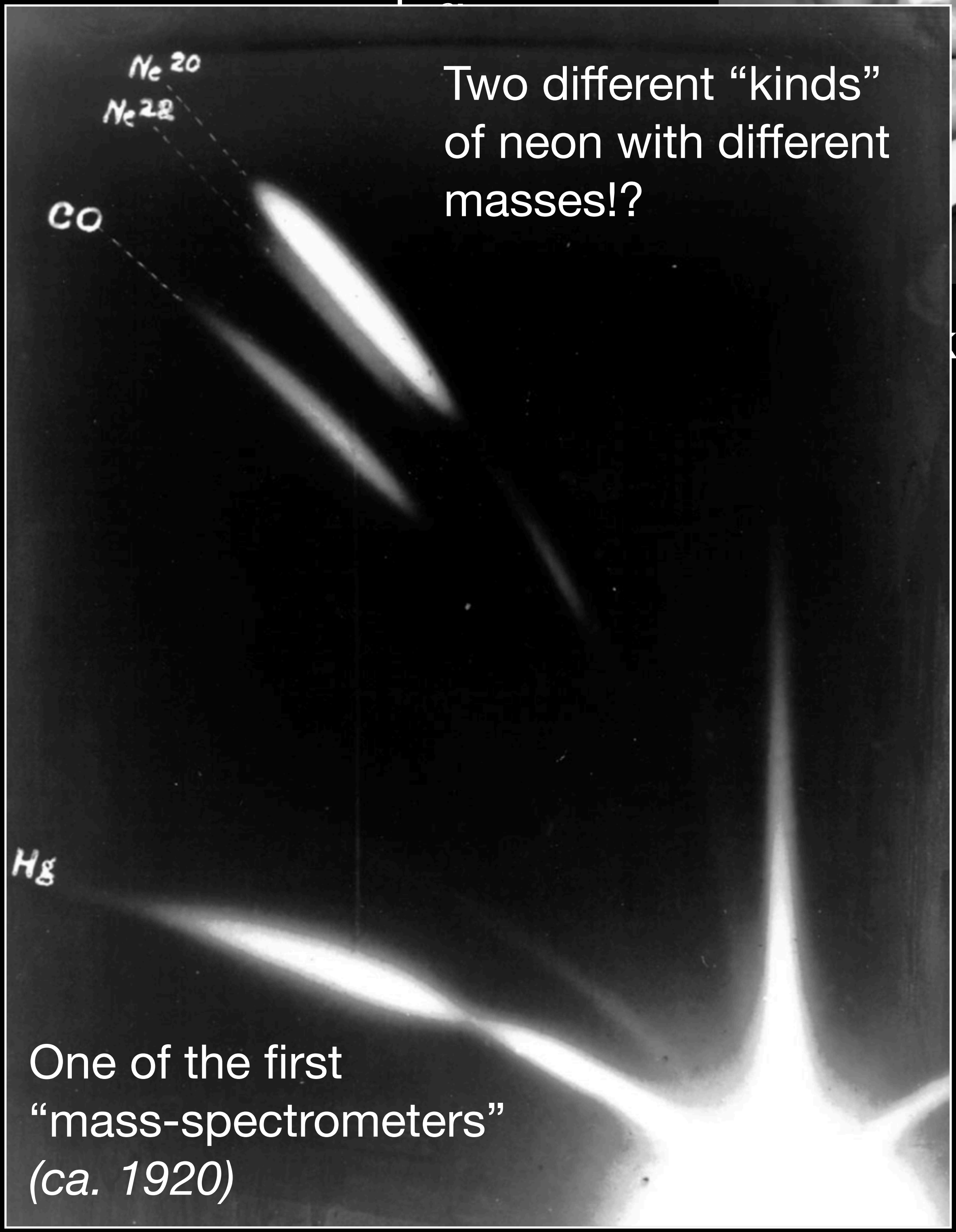
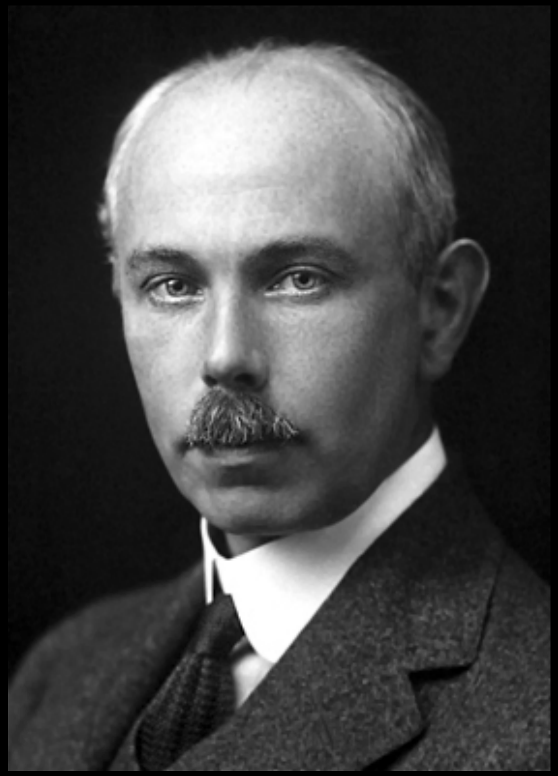


Two different “kinds” of neon with different masses!?

One of the first “mass-spectrometers” *(ca. 1920)*



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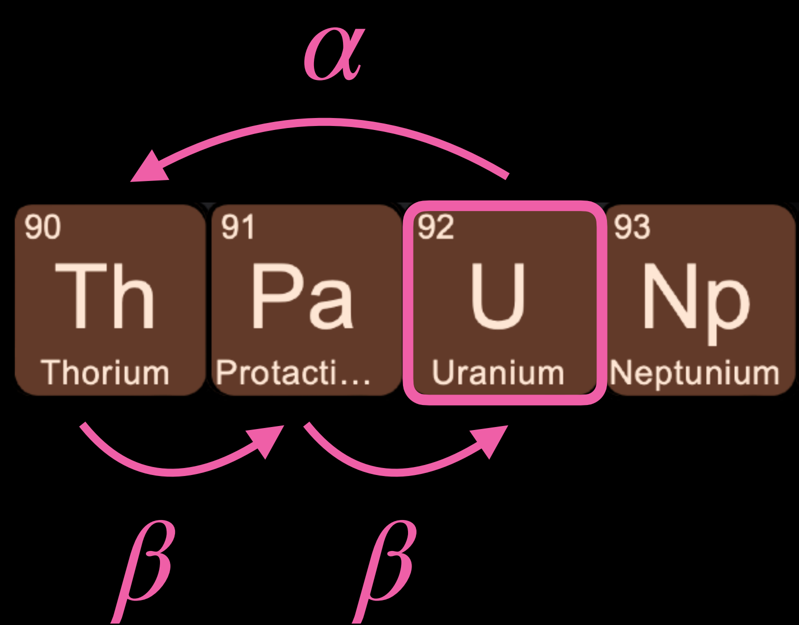

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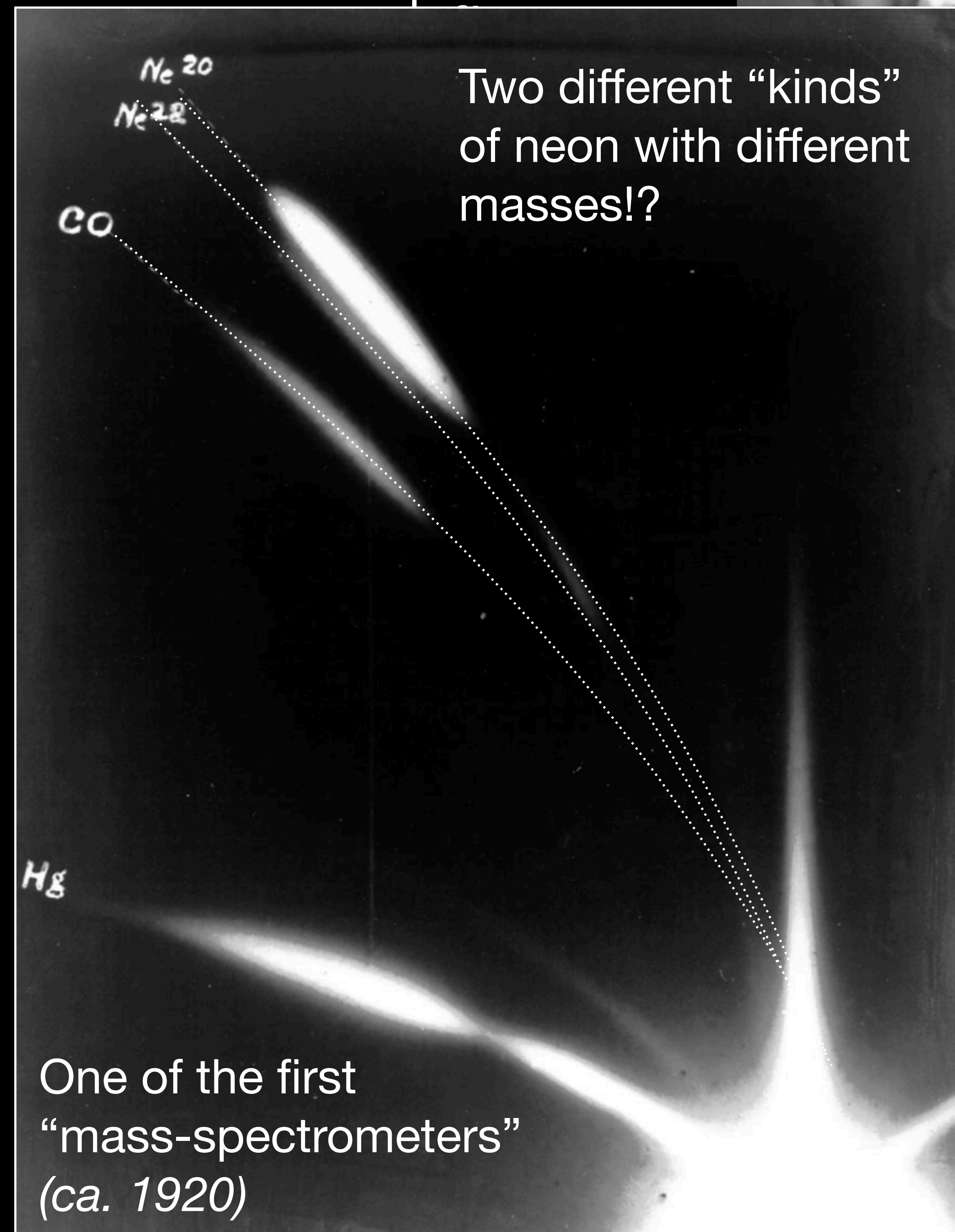

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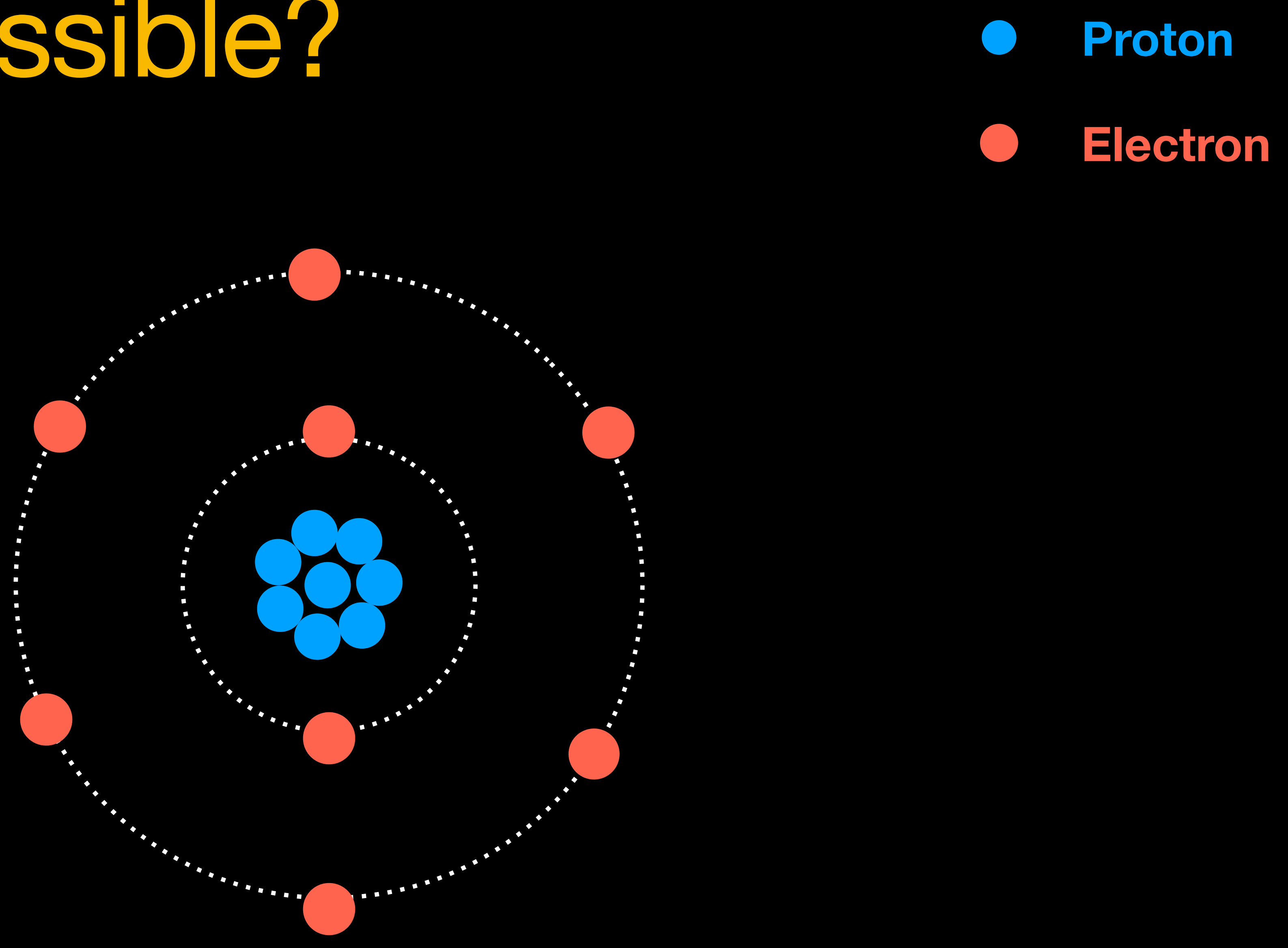

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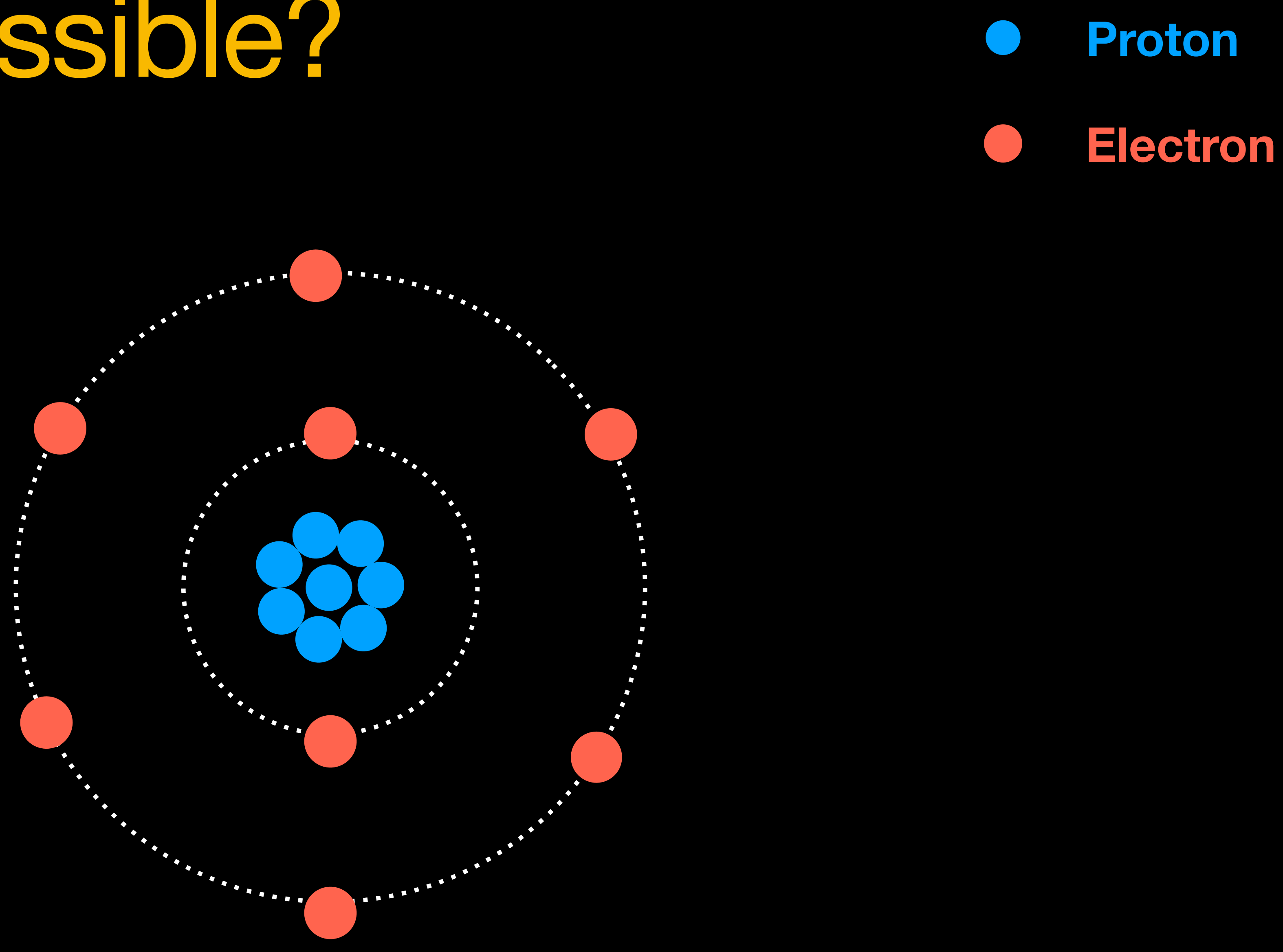

But: adding another proton + electron turns it into a different (heavier) element …

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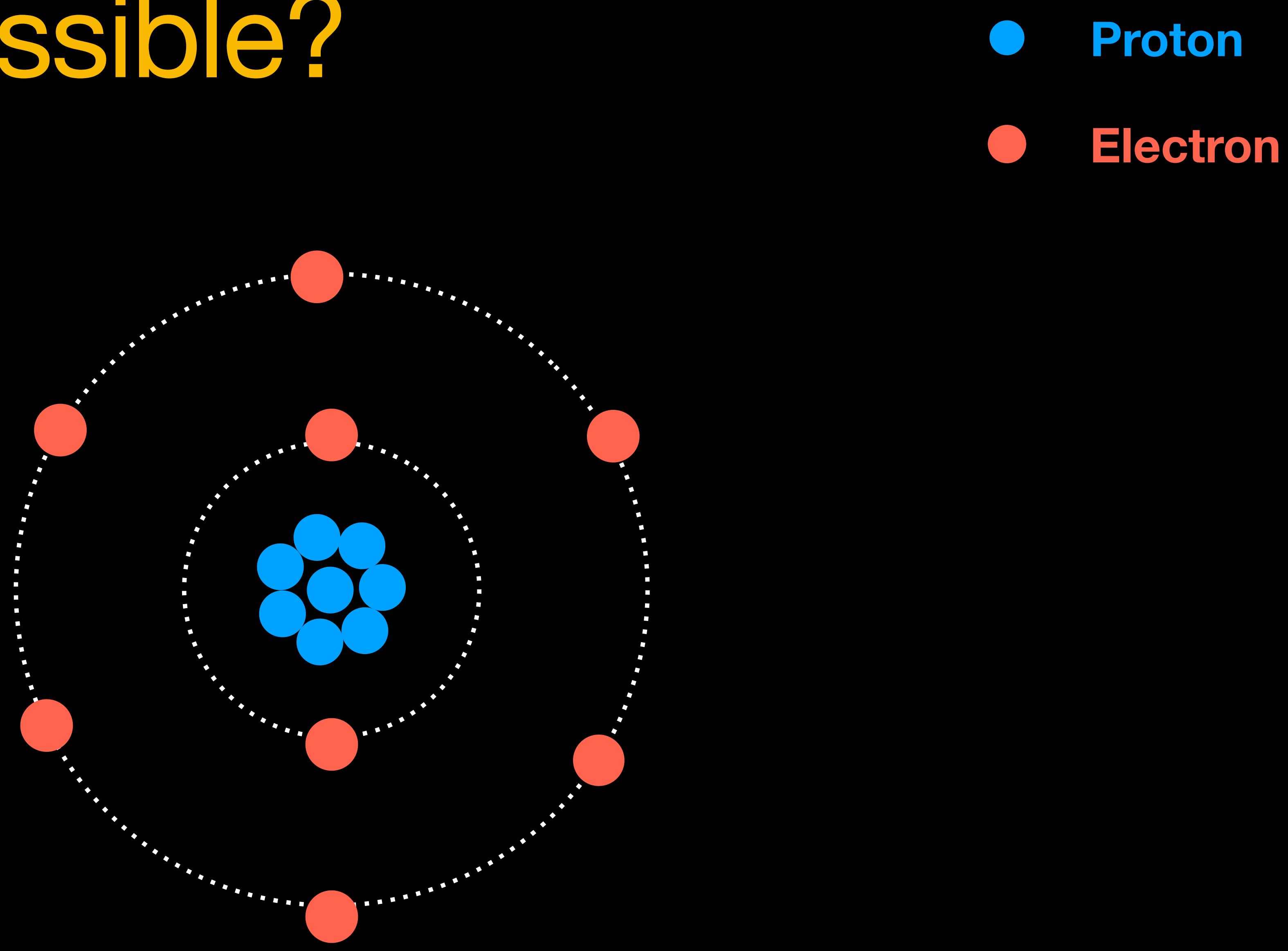

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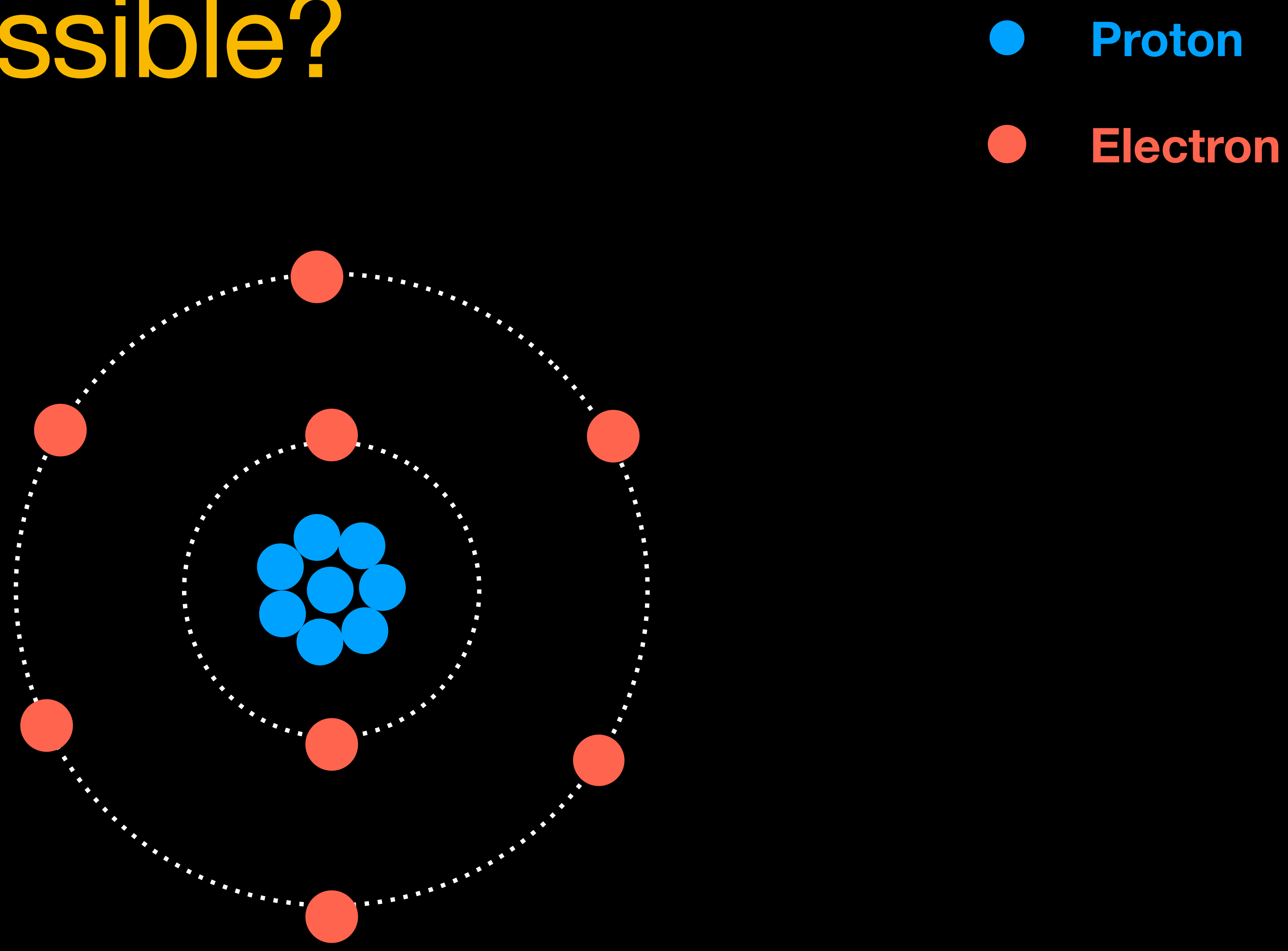

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What's wrong?

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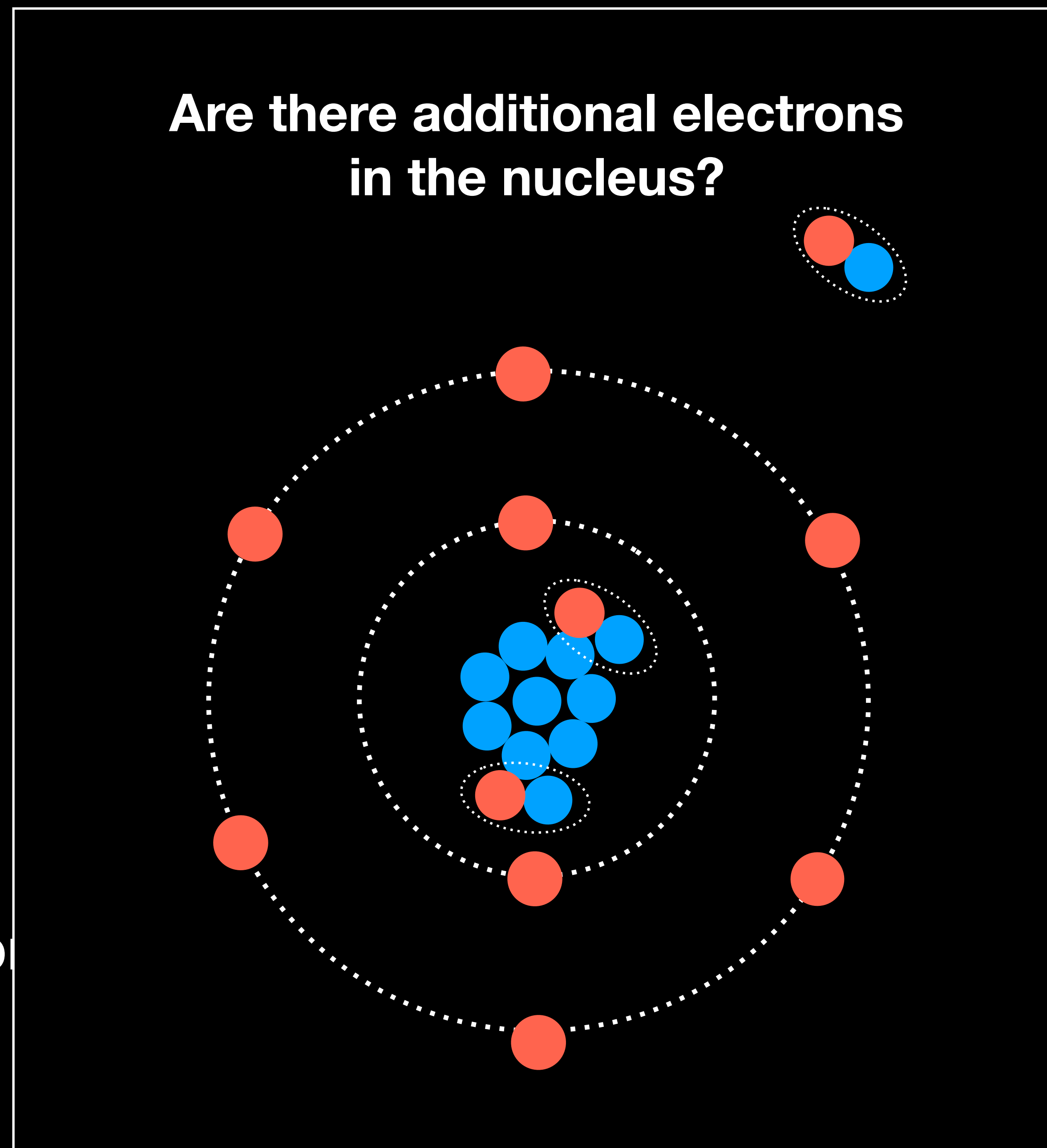
Electron



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What's wrong?

A new neutral particle?

1932

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James Chadwick

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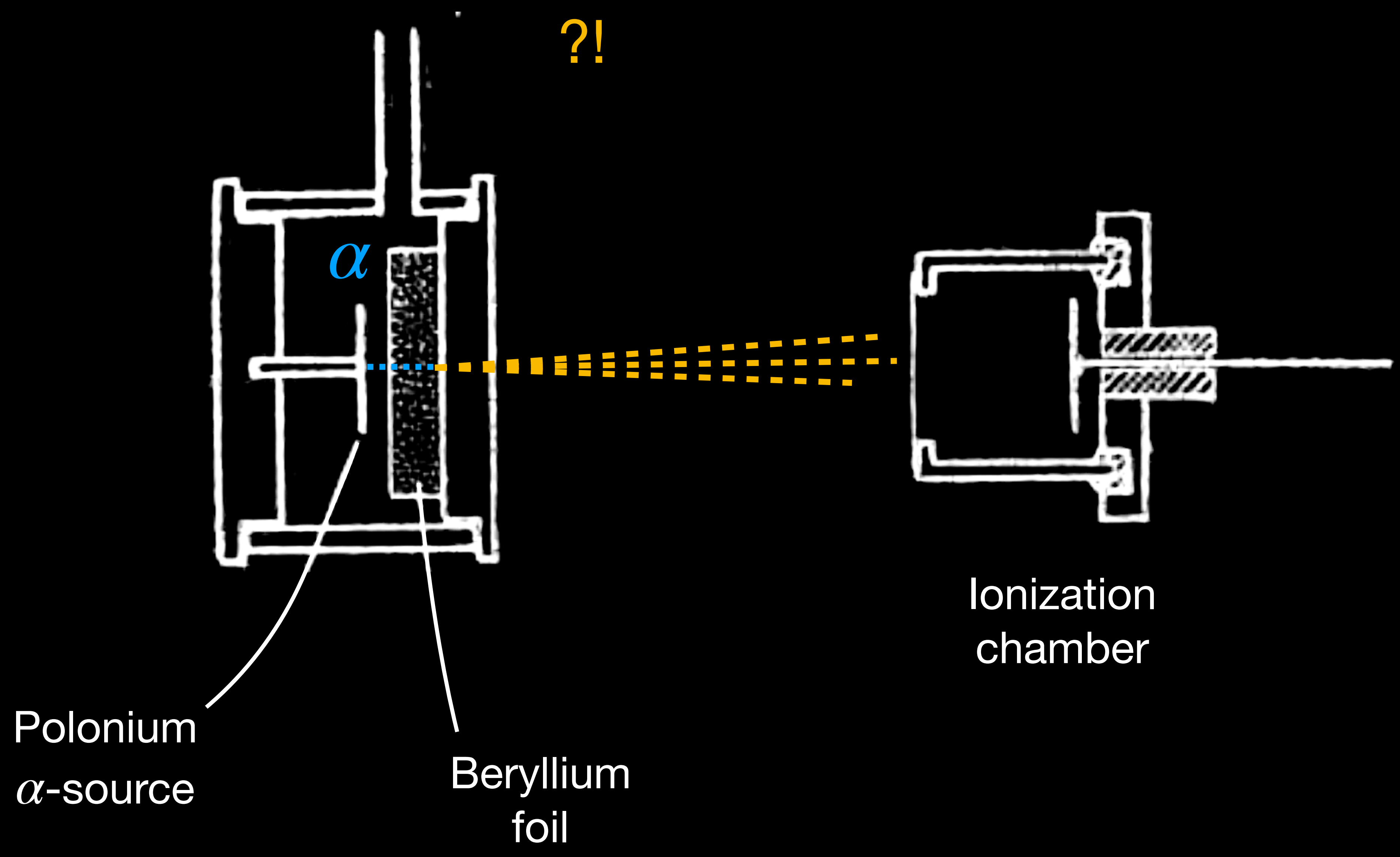
Frédéric and Irène Joliot-Curie

A new particle?

1932



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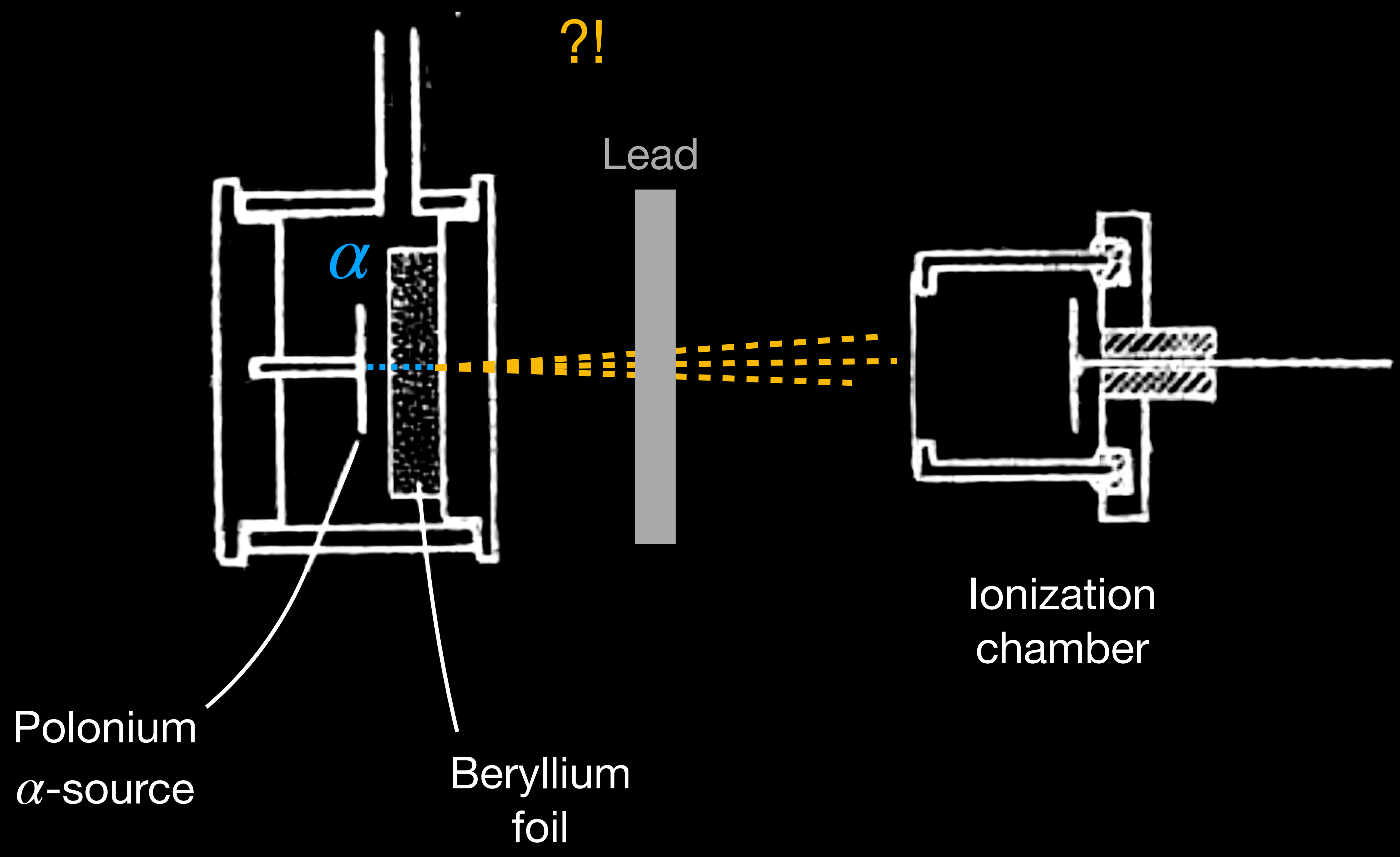

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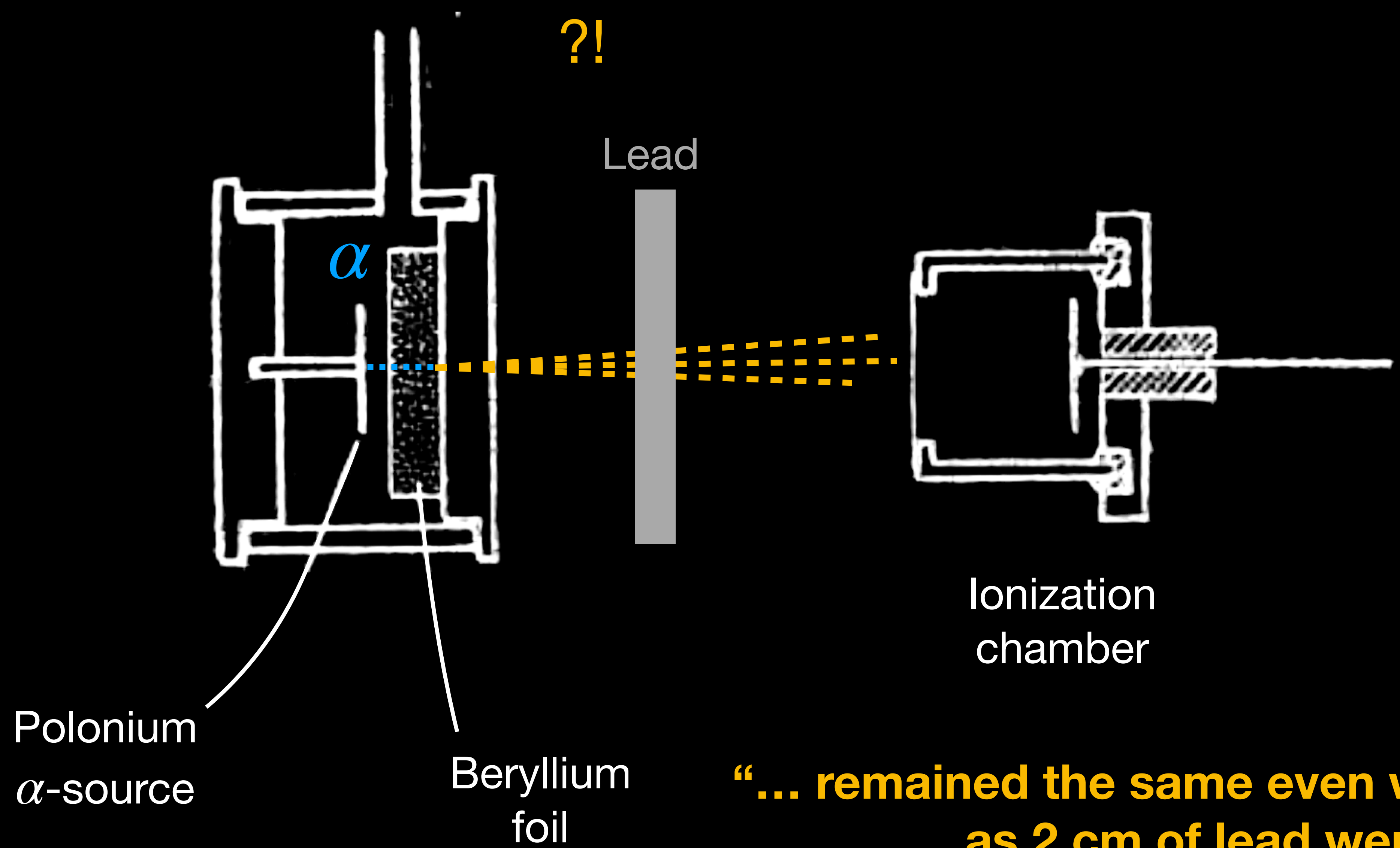


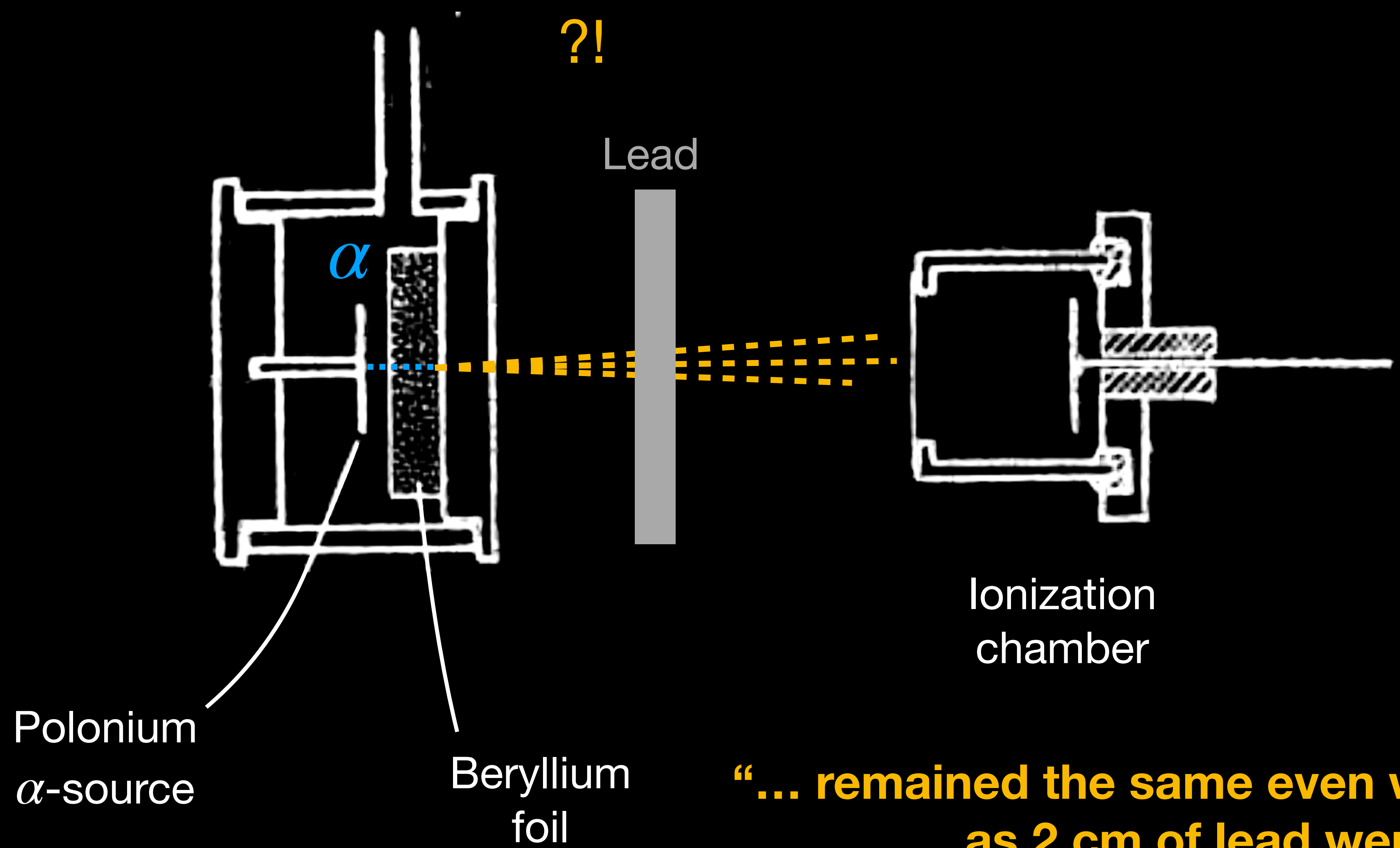
"… remained the same even when as much as 2 cm of lead were inserted …"

→ *very penetrating radiation*

A new particle?

1932

"In order to explain the great penetrating power of the radiation we must assume that the particle has ***no net charge****. "*



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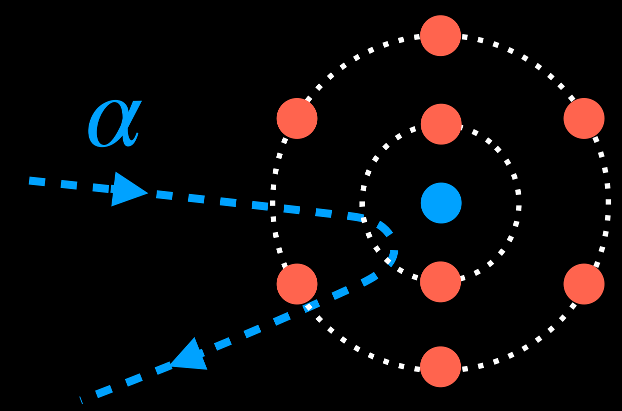

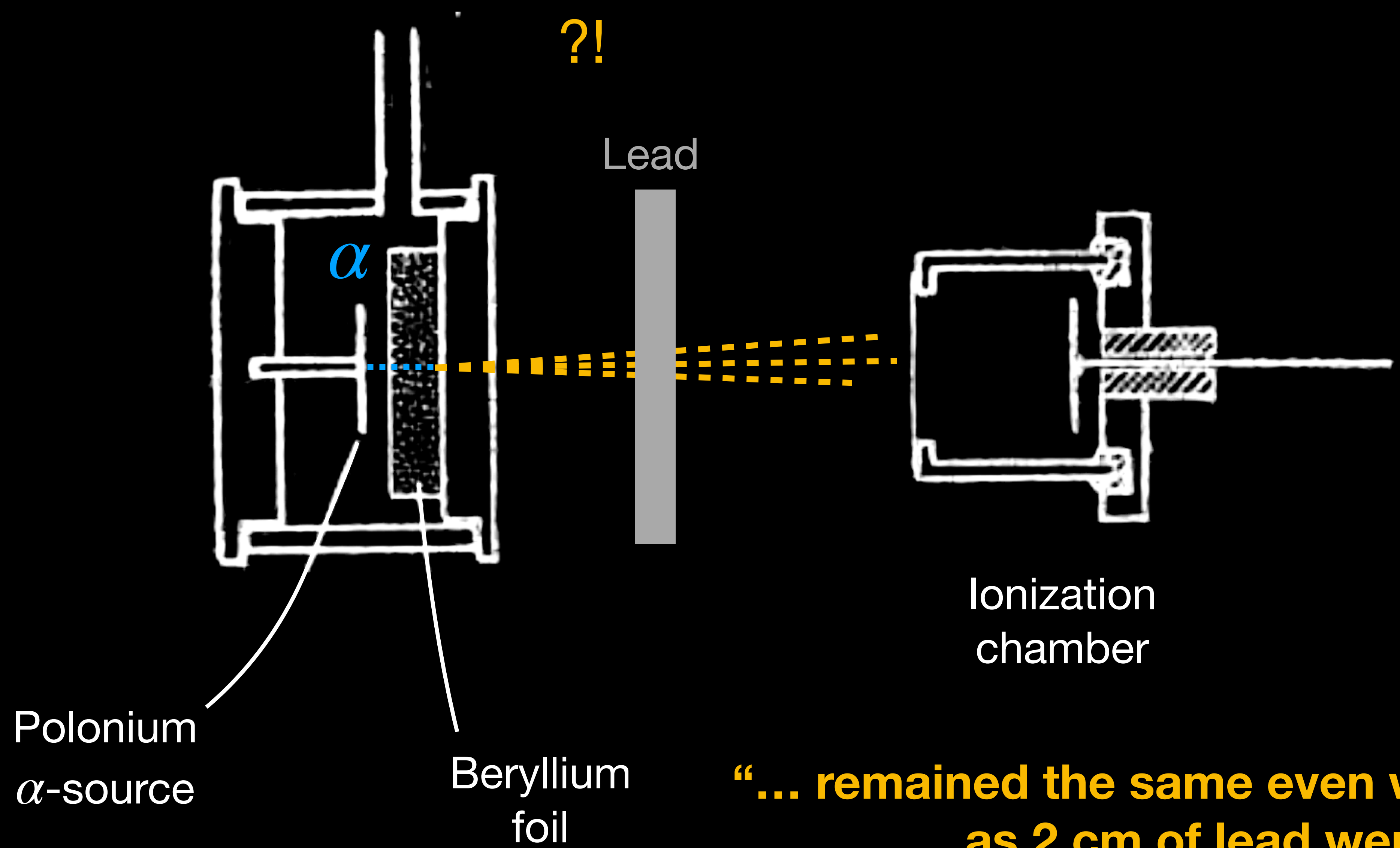

"… remained the same even when as much as 2 cm of lead were inserted …"

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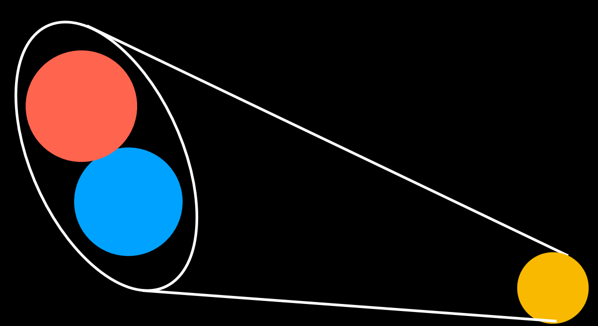
Which kind of neutral particle?

Chadwick (1932):

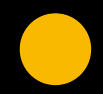
“It is concluded that the radiation consists of neutrons, particles of mass 1, and charge 0.”

(The Joliot-Curies missed a major discovery!)

But what kind of neutron?



Proton and electron
tightly bound together



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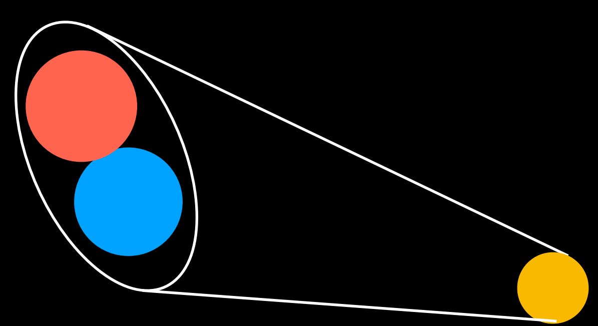

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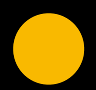

New particle
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Chadwick + Goldhaber (1935):

Mass of neutron <u>larger</u> than proton and electron taken together!

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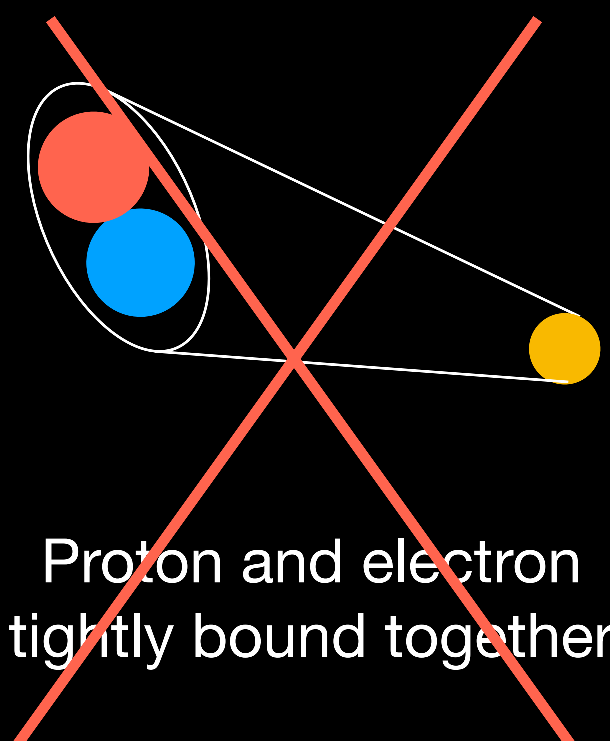

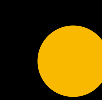

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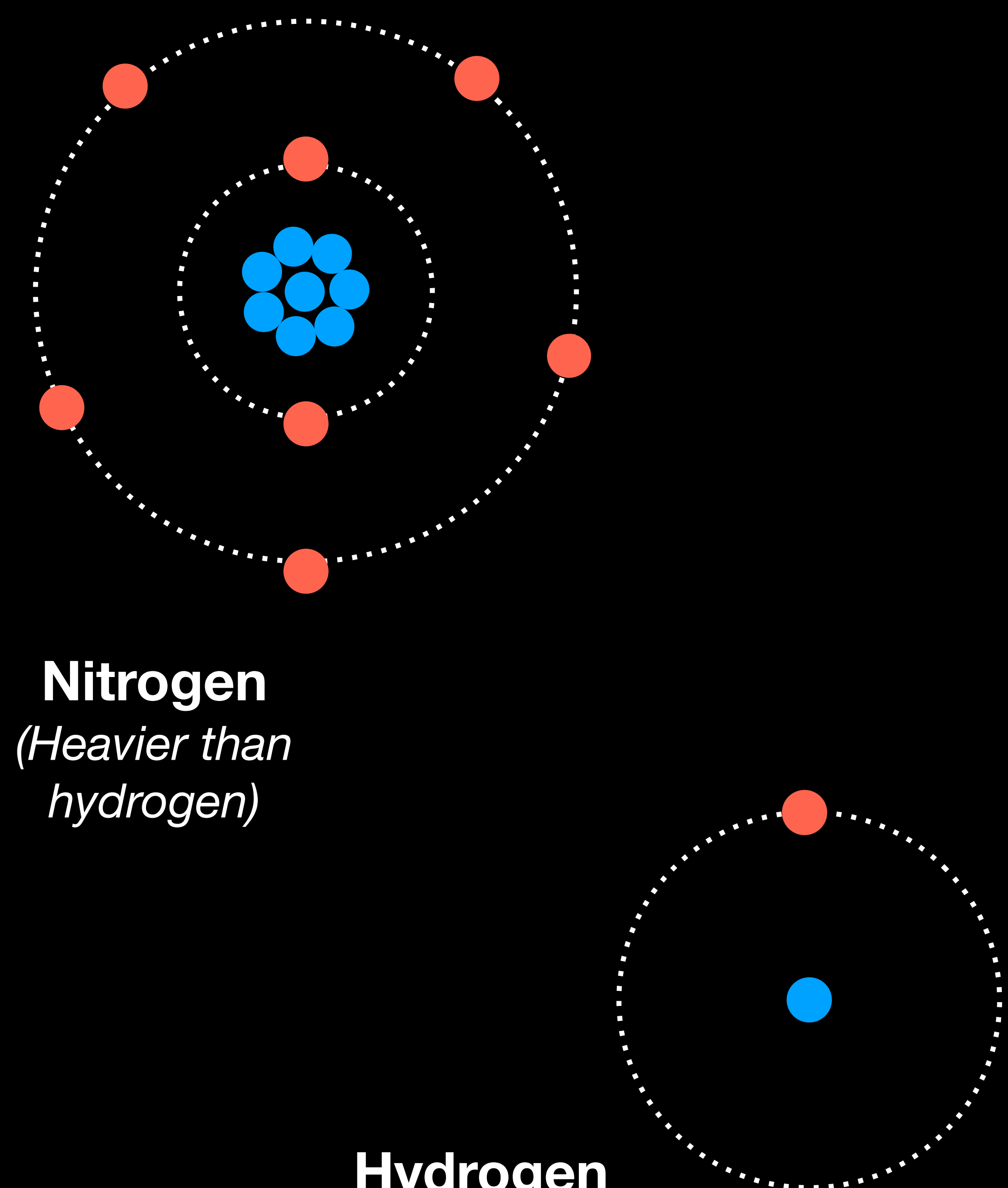
Mass of neutron larger than proton and electron taken together!

An updated view of the atom

Proton
Neutron
Electron



An updated view of the atom

- Proton
- Neutron
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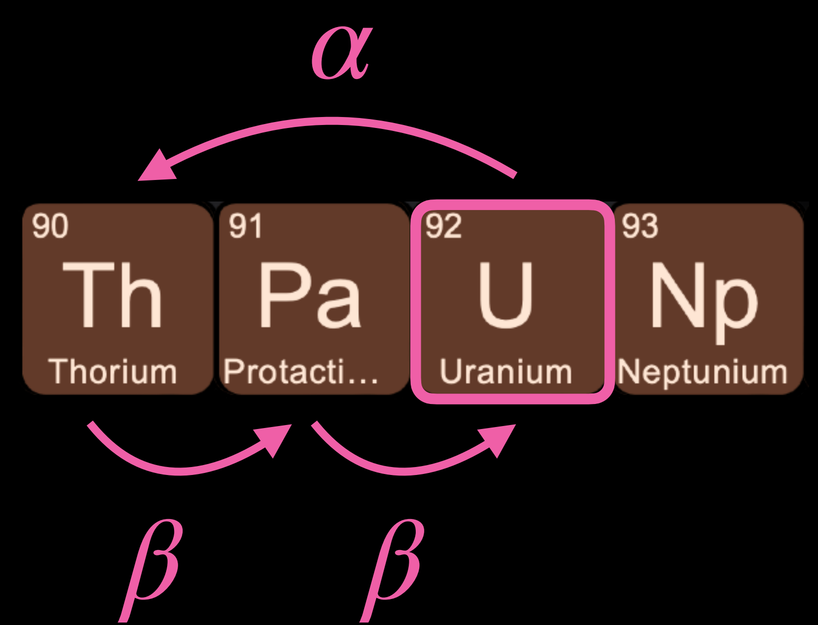
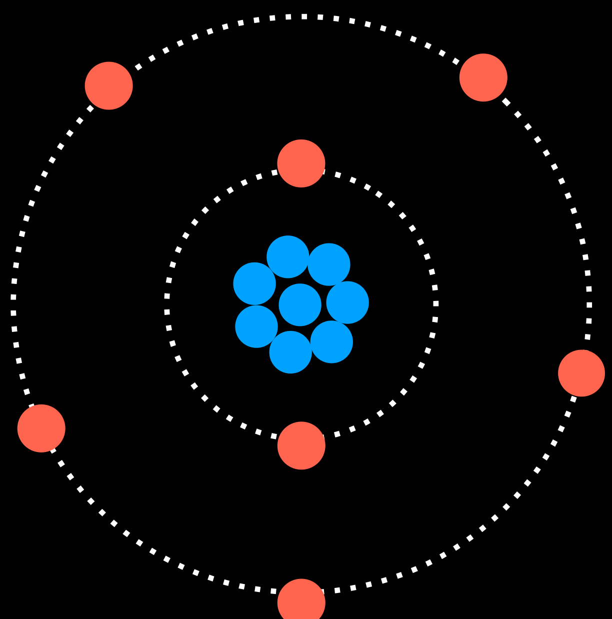


Soddy's "different kinds of uranium" contain different numbers of neutrons!



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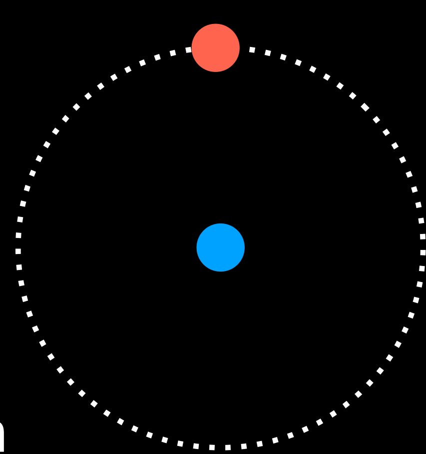

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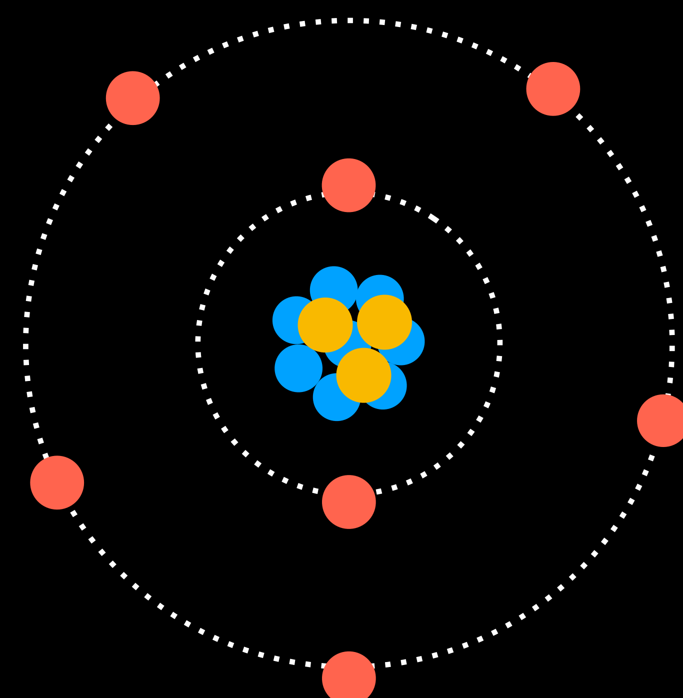
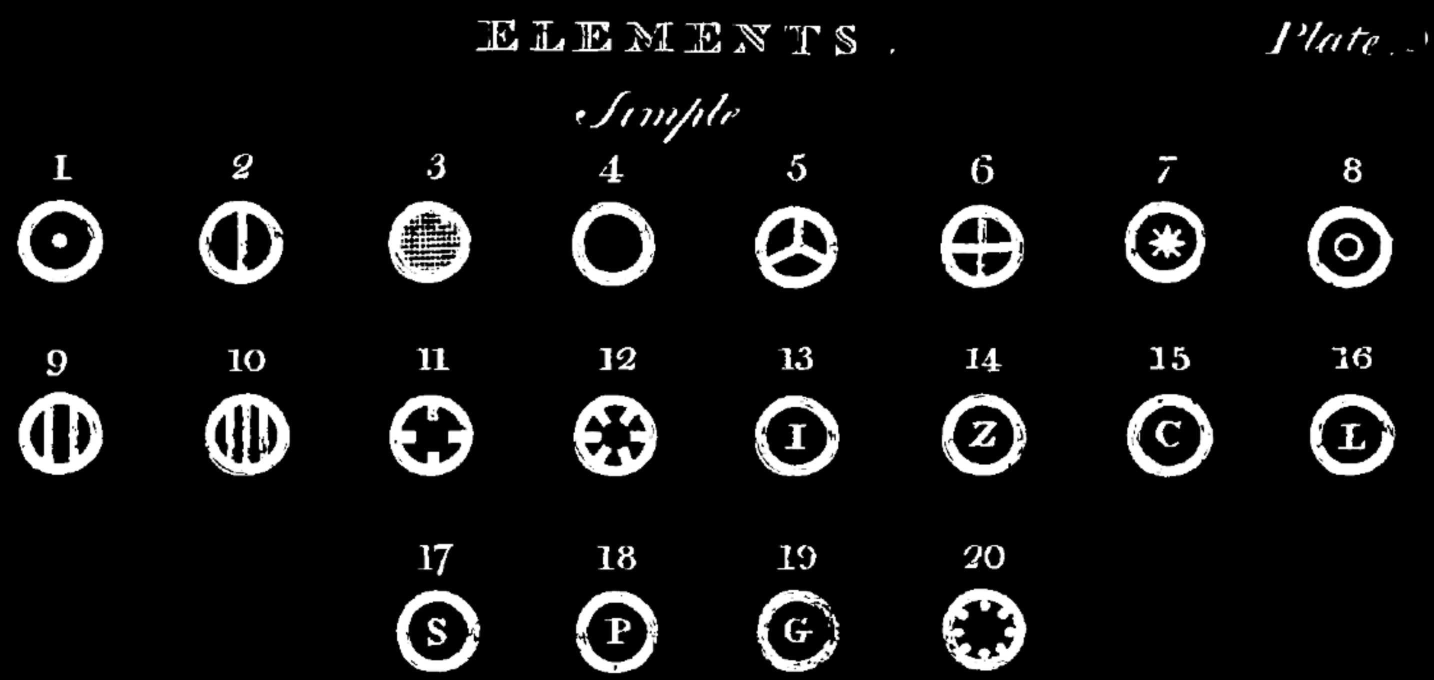
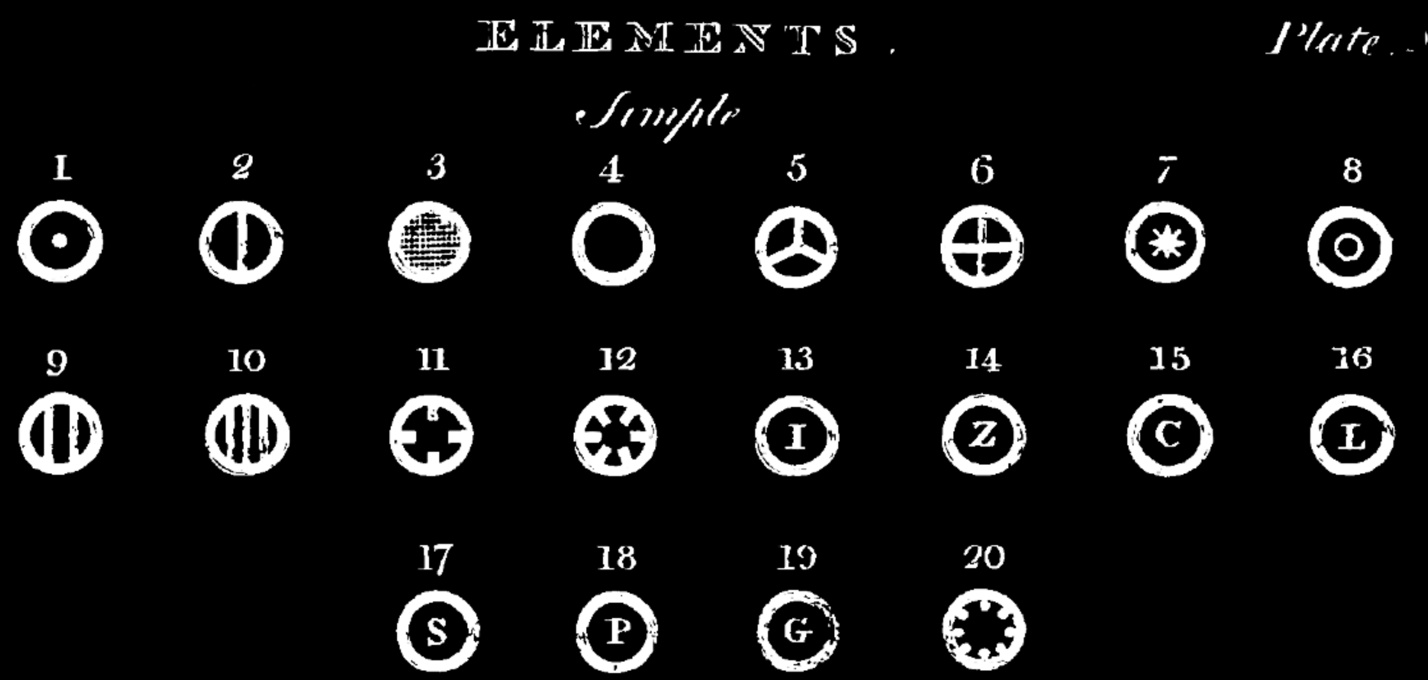




Dalton, 1808:

“The atoms of such bodies are conceived at present to be simple.”



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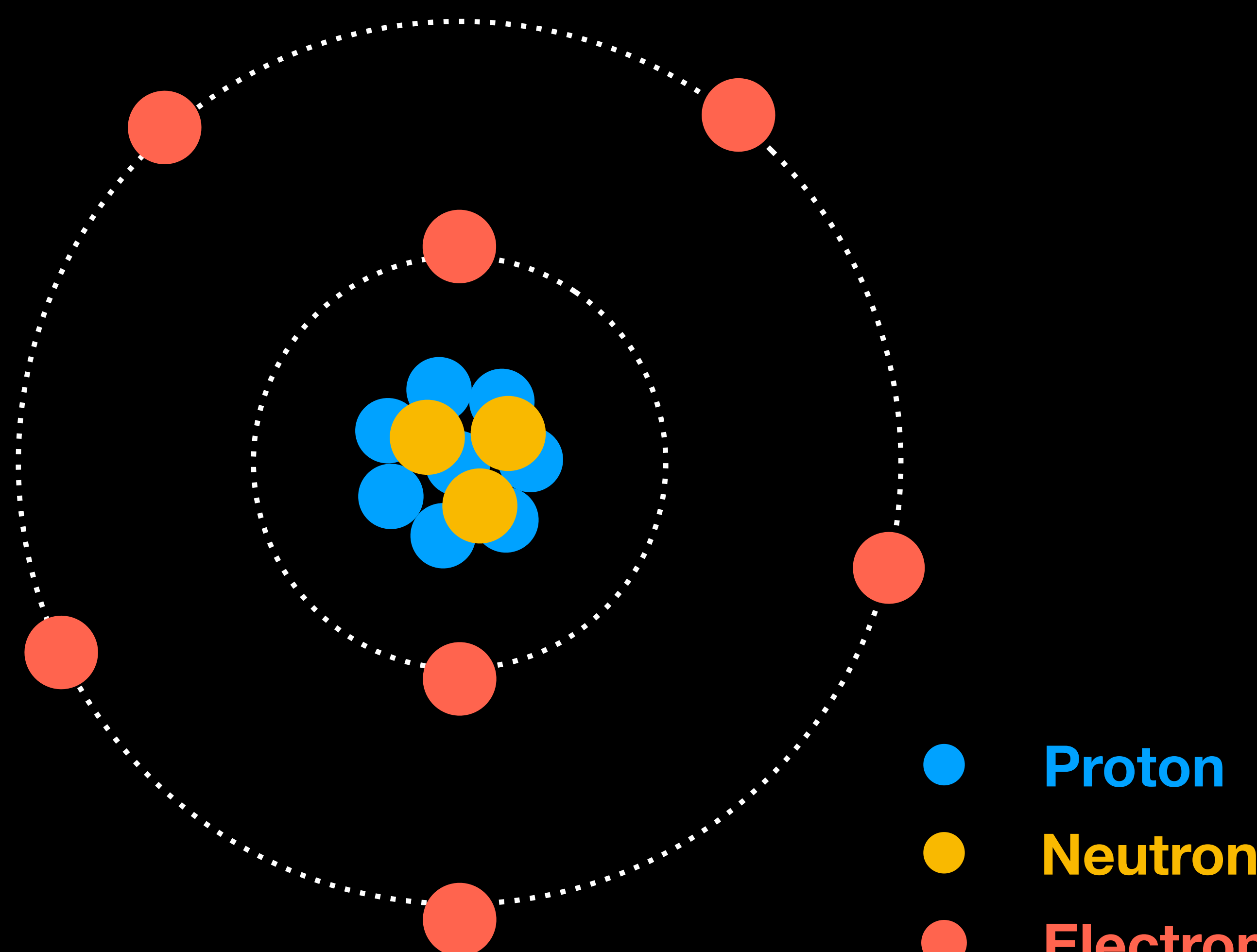
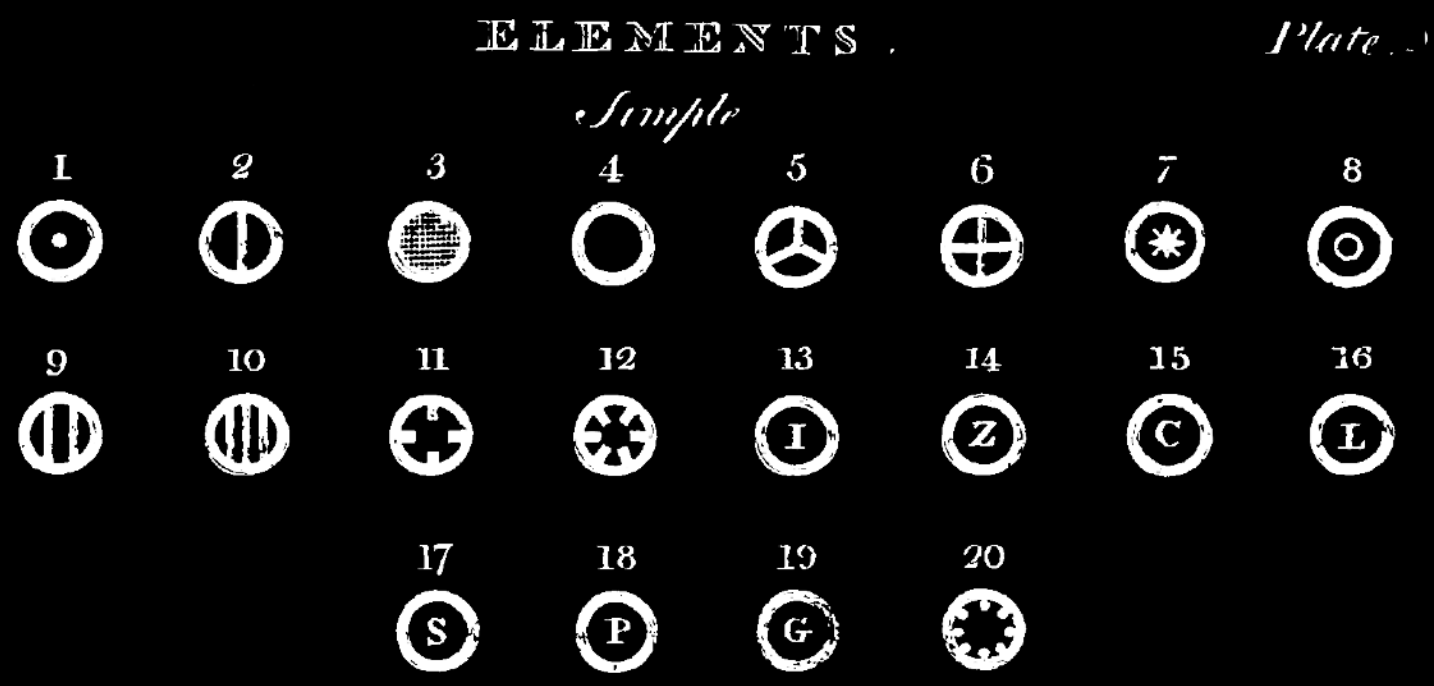
Atoms are everything but simple!





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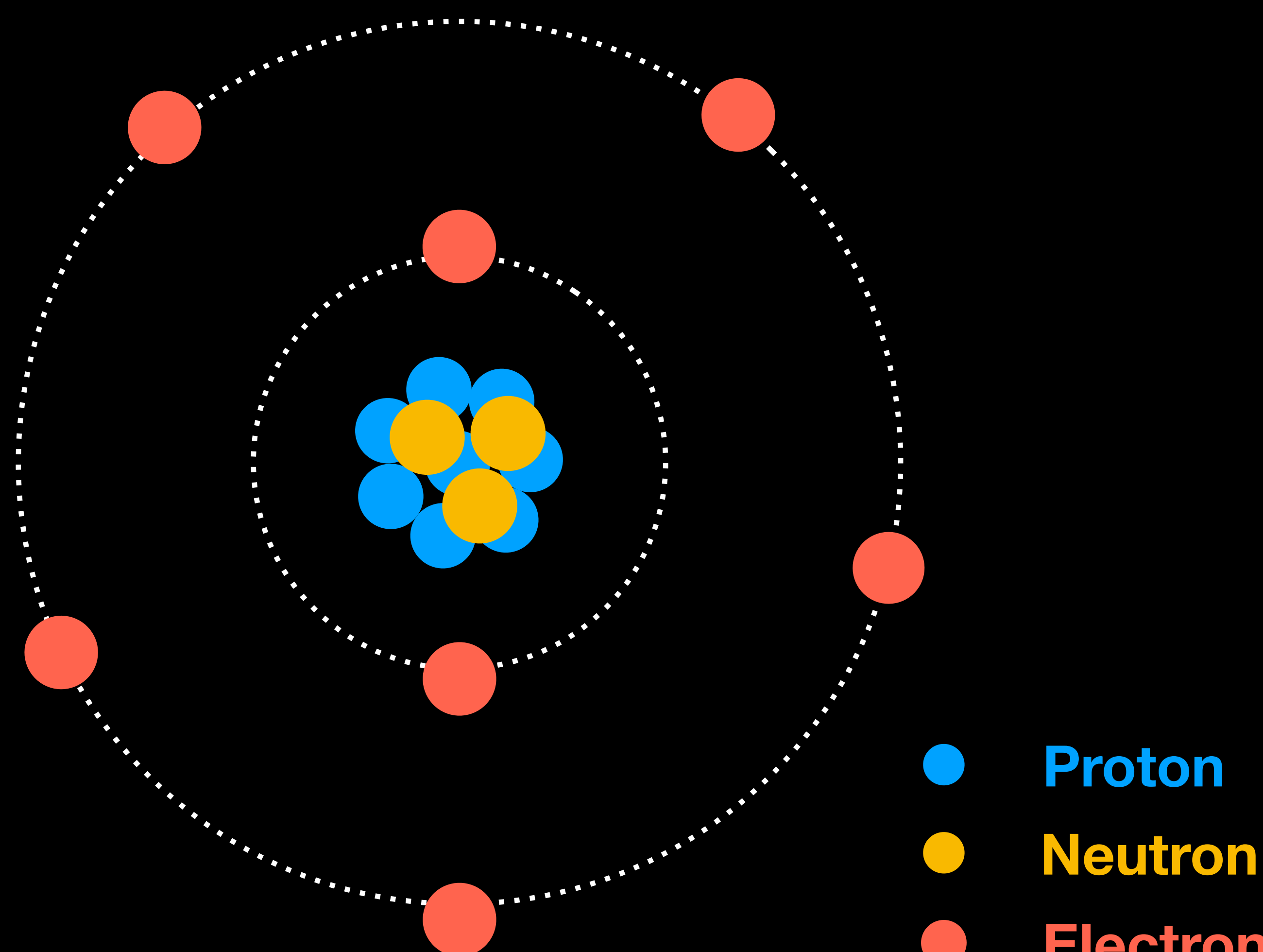
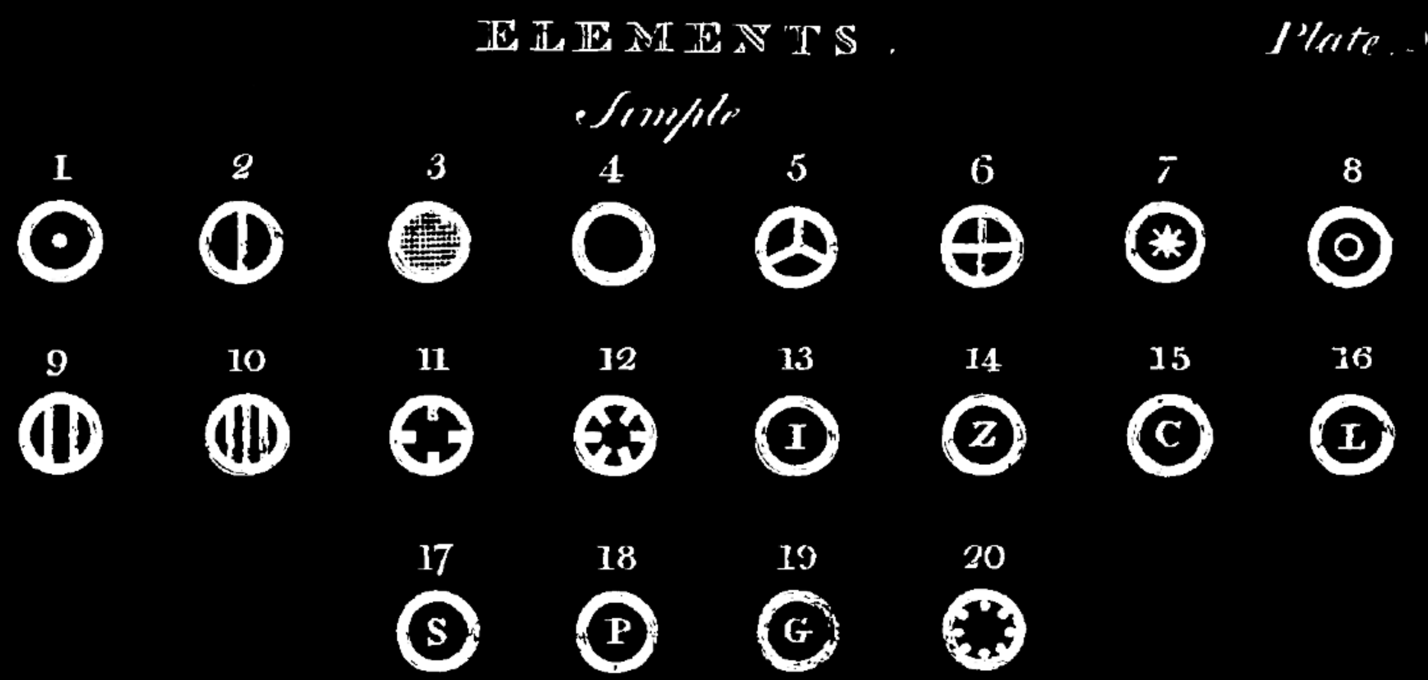


And again, changes in our worldview are going to have big consequences …



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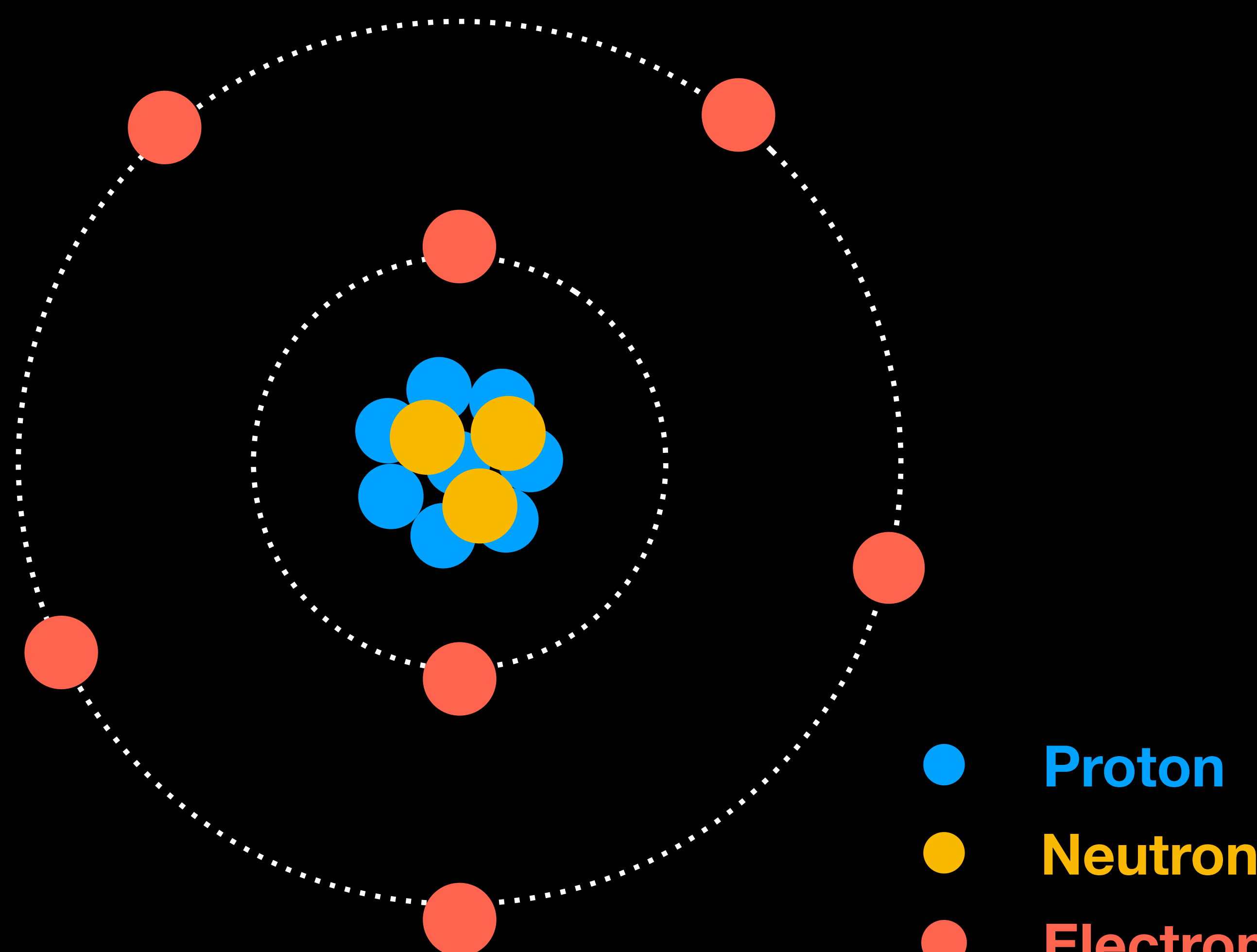

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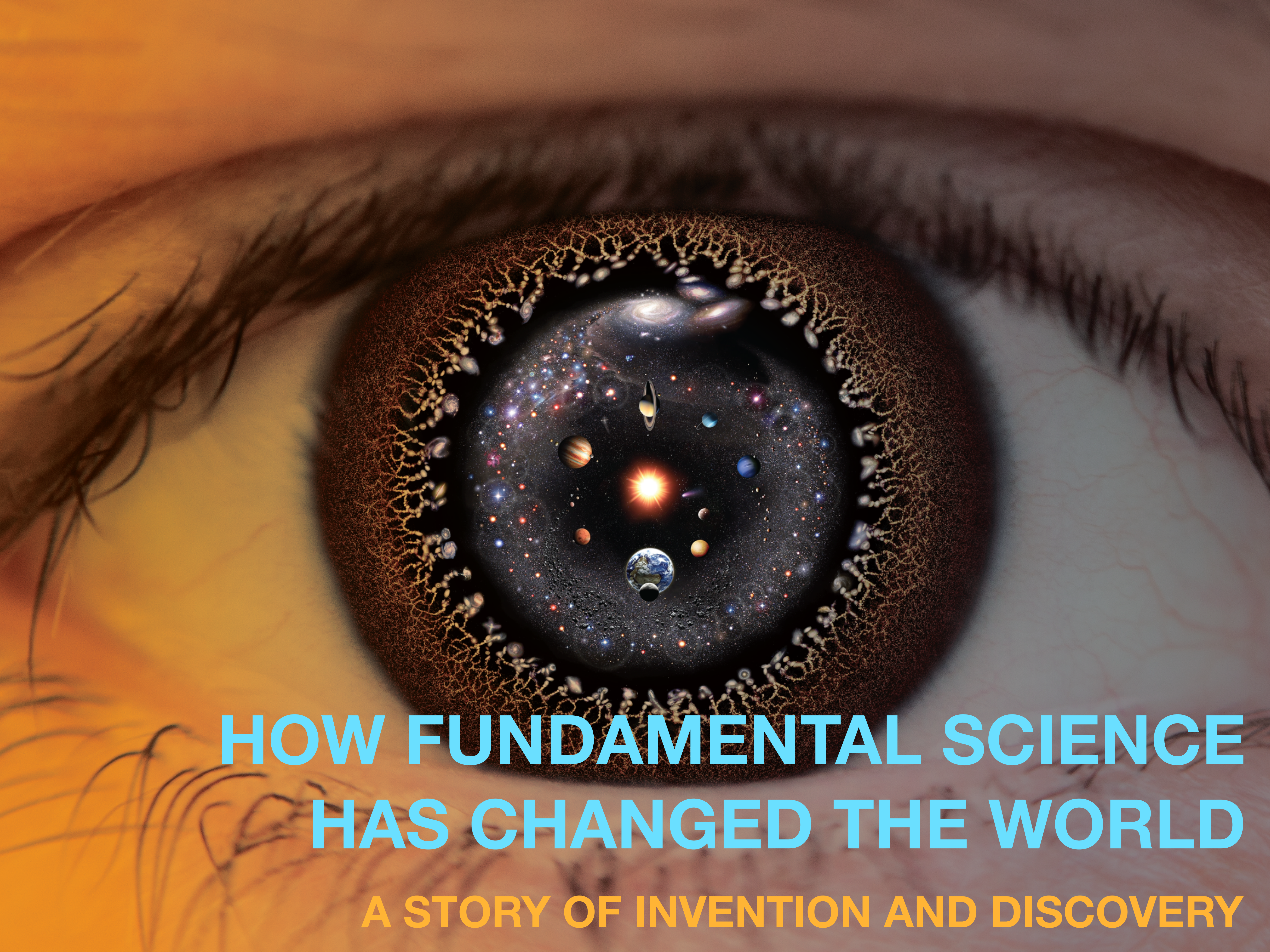
… next time!



HOW FUNDAMENTAL SCIENCE HAS CHANGED THE WORLD

A STORY OF INVENTION AND DISCOVERY