Physics around 1900

Vom Relativen zum Absoluten.

(Gastvorlesung, gehalten in der Universität München, am 1. Dezember 1924.)

Eure Magnifizenz! Meine hochverehrten Damen und Herren! Es ist mir eine hohe Ehre und eine ganz besondere Freude, daß es mir durch eine freundliche Einladung verstattet ist, hier in diesem Hause, in dem ich vor fünfzig Jahren als akademischer Bürger einziehen durfte, in dem ich später den Doktorgrad und dann die Venia legendi erwarb, wieder einmal das Wort ergreifen und über Gegenstände meiner Wissenschaft reden zu dürfen. Unwillkürlich lenkt sich dabei der Blick zurück auf den ehemaligen Stand der wissenschaftlichen Forschung und ermißt den gewaltigen Abstand, der sich bei der Vergleichung der beiderseitigen Bilder, dem von früher und dem von heute, dem inneren Auge offenbart. Wohl kaum in irgendeinem halben Jahrhundert hat die Physik ihr Antlitz so von Grund auf und so vollkommen unerwartet gewandelt. Als ich meine physikalischen Studien begann und bei meinem ehrwürdigen Lehrer Philipp v. Jolly wegen der Bedingungen und Aussichten meines Studiums mir Rat erholte, schilderte mir dieser die Physik als eine hochentwickelte, nahezu voll ausgereifte Wissenschaft, die nunmehr, nachdem ihr durch die Entdeckung des Prinzips der Erhaltung der Energie gewissermaßen die Krone aufgesetzt sei, wohl bald ihre endgültige stabile Form angenommen haben würde. Wohl gäbe es vielleicht in einem oder dem anderen Winkel noch ein Stäubchen oder ein Bläschen zu prüfen und einzuordnen, aber das System als Ganzes stehe ziemlich gesichert da, und die theoretische Physik nähere sich merklich demjenigen Grade der Vollendung, wie ihn etwa die Geometrie schon seit Jahrhunderten besitze.

Das war vor fünfzig Jahren die Anschauung eines auf der Höhe der Zeit stehenden Physikers. Zwar fehlte es schon damals in der physikalischen Wissenschaft nicht an gewissen dunklen, einer näheren Aufklärung bedürftigen Punkten, die in den behaglichen Zustand der Sättigung etwas Beunruhigendes brachten. So trotzte das sonderbare Verhalten des Lichtäthers hartnäckig allen auf seine Erklärung abzielenden Versuchen, und das Phänomen der um jene Zeit von Wilh. Hittorf entdeckten Kathodenstrahlen gab den Experimentatoren und den Theoretikern schwierige Rätsel auf. Noch Heinrich Hertz, das letzte strahlende Gestirn am Firmament der klassischen Physik, brachte die Kathodenstrahlen in Zusammenhang mit longitudinalen Ätherwellen, da es ihm mit den damals zur Verfügung

"When I was beginning to study physics and asked my venerable teacher Philip von Jolly for his opinion concerning the conditions and perspectives of my studies, he presented physics as a highly developed and almost fully mature science, which after its achievements had been crowned by the principle of conservation of energy, was shortly to assume its final form. True enough, in some corners there remained a speck or little bubble to be studied and removed, but the system itself was quite safe and theoretical physics was approaching perfection which since centuries was the attribute of geometry."

Max Planck, Munich lecture (1924)

”Peter Zeeman, who received the Nobel prize in physics for 1902, enjoyed telling that he had been warned not to study physics: ‘Physics is no longer a promising subject; it is finished, there is no room for anything really new’. It must have been around 1883.”

Hendrik Casimir - *Haphazard Reality*

”The more important fundamental laws and facts of physical science have all been discovered, and these are so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote”

Albert A. Michelson (1894)

”Le monde est aujourd’hui sans mystère”

(”The world today is without mystery”)

Marcelin Berthelot (1885)

”Theory of light based on the works of Fresnel and his successors is the most perfect of all the theories of physics”

Henri Poincaré - *Teorie mathématique de la lumière*, Paris 1889

The original documents leave little doubt that the physicists active around 1900 were mostly satisfied with classical physics and saw little need for ’new’ physics

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE

[SIXTH SERIES.]

JULY 1901.

Nineteenth Century Clouds over the Dynamical Theory of Heat and Light *. *By* The Right. Hon. Lord KELVIN, *G.C.V.O., D.C.L., LL.D., F.R.S., M.R.I.* †.

[IN the present article, the substance of the lecture is reproduced—with large additions, in which work commenced at the beginning of last year and continued after the lecture, during thirteen months up to the present time, is described—with results confirming the conclusions and largely extending the illustrations which were given in the lecture. I desire to take this opportunity of expressing my obligations to Mr. William Anderson, my secretary and assistant, for the mathematical tact and skill, the accuracy of geometrical drawing, and the unfailingly faithful perseverance in the long-continued and varied series of drawings and algebraic and arithmetical calculations, explained in the following pages. The whole of this work, involving the determination of results due to more than five thousand individual impacts, has been performed by Mr. Anderson.—K., Feb. 2, 1901.]

§ 1. THE beauty and clearness of the dynamical theory, which asserts heat and light to be modes of motion, is at present obscured by two clouds. I. The first came into existence with the undulatory theory of light, and

* Lecture delivered at the Royal Institution of Great Britain, on Friday, April 27, 1900.
† Communicated by the Author.

THE

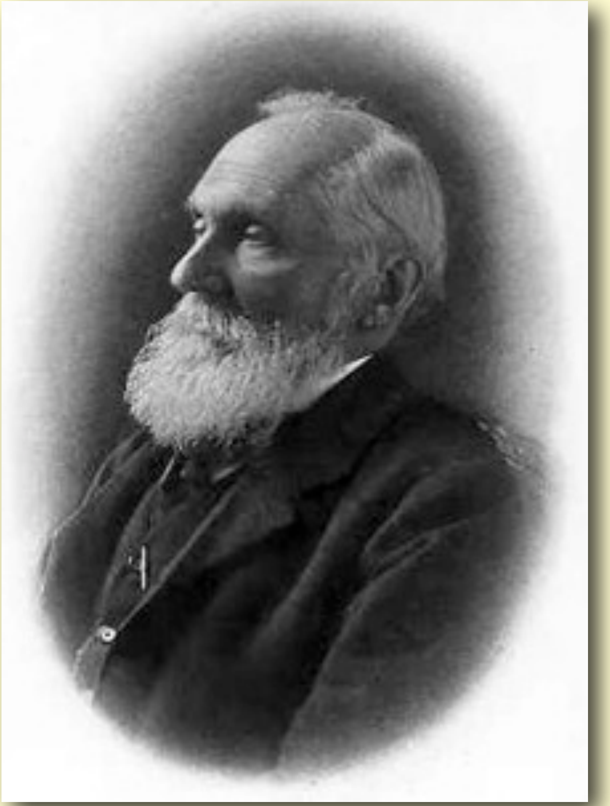
LONDON, EDINBURGH, AND DUBLIN

"The beauty and clearness of the dynamical theory, which asserts heat and light to be modes of motion, is at present obscured by two clouds. I. The first came into existence with the undulatory theory of light, and was dealt with by Fresnel and Dr. Thomas Young; it involved the question, how could the earth move through an elastic solid, such as essentially is the luminiferous ether? II. The second is the Maxwell-Boltzmann doctrine regarding the partition of energy."

§ 1. THE beauty and clearness of the dynamical theory, which asserts heat and light to be modes of motion, is at present obscured by two clouds. I. The first came into existence with the undulatory theory of light, and

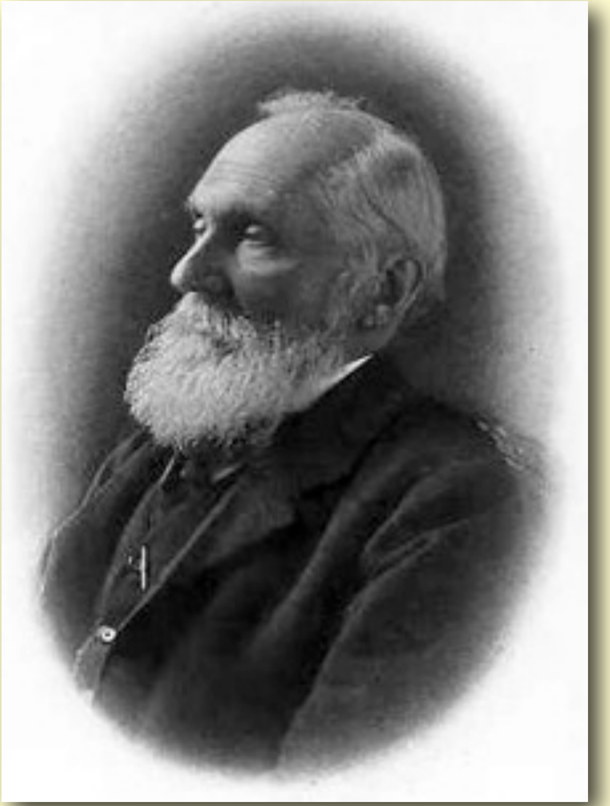
* Lecture delivered at the Royal Institution of Great Britain, on Friday, April 27, 1900.
† Communicated by the Author.

”One word characterizes the most strenuous of the efforts for the advancement of science that I have made perseveringly during fifty-five years; that word is <u>failure</u>. I know no more of electric and magnetic forces or of the relation between ether, electricity, and ponderable matter, or of chemical affinity, than I knew and tried to teach to my students of natural philosophy fifty years ago in my first session as professor”.



Lord Kelvin's Jubilee, *Nature* **54**, 173-181 (1896)

”Something of sadness must come of failure; but in the pursuit of science, inborn necessity to make the effort brings with it much of the *certaminis gaudia* - and saves the naturalist from being wholly miserable, perhaps even allows him to be fairly happy, in his daily work. And what splendid compensations for philosophical failures we have had in the admirable discoveries by observation and experiment on the properties of matter, and in the exquisitely beneficent applications of science to the use of mankind with which these fifty years have so abounded!”



Lord Kelvin's Jubilee, *Nature* **54**, 173-181 (1896)

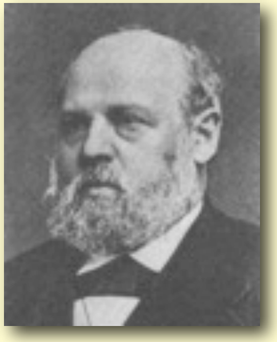
X rays and radioactivity

Cathode rays

1859

discovery of radiation emanating from the cathode in ‘Geissler tubes’

Heinrich Geissler



Julius Plücker

1869

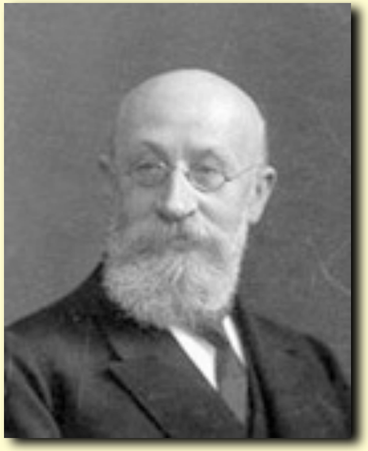
Johann Wilhelm Hittorf – the rays emitted from the cathode (*Glimmstrahlen*) propagate along straight lines, may form shadows, but undergo deflection in the magnetic field

Cathode rays

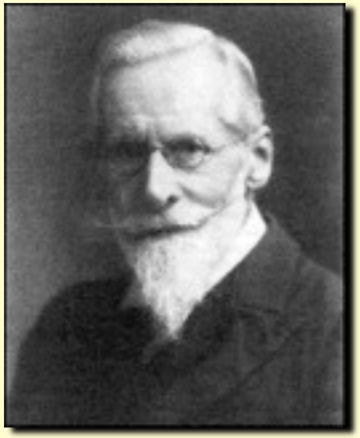
this radiation
is corpuscular
(1871)

Cromwell Varley

'cathode rays'
(1876)



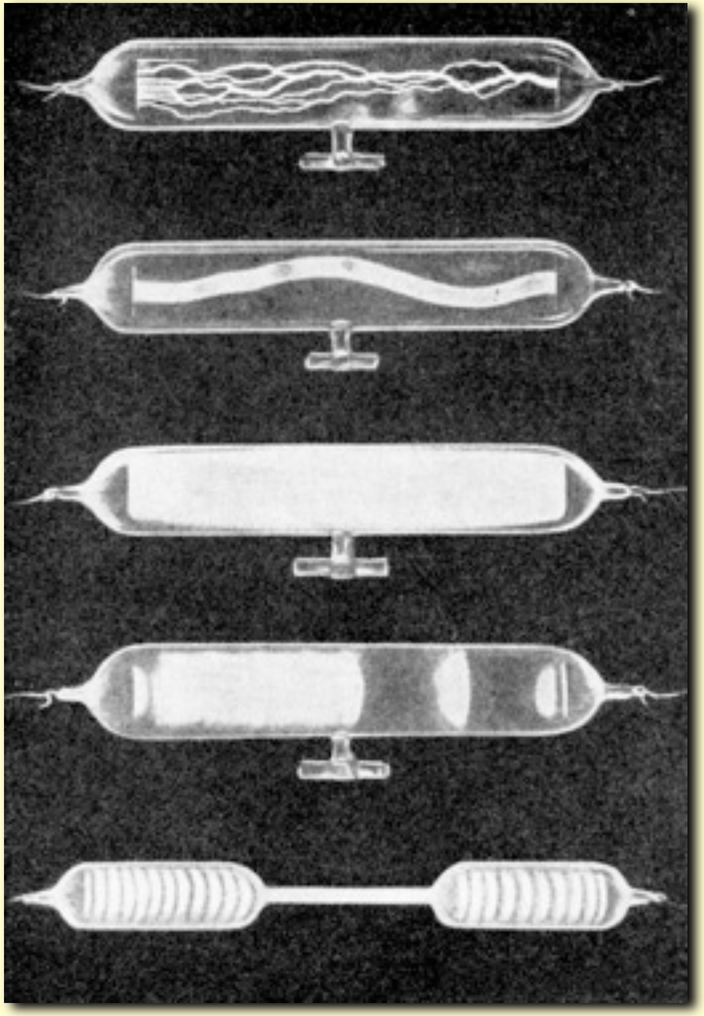
Eugene Goldstein

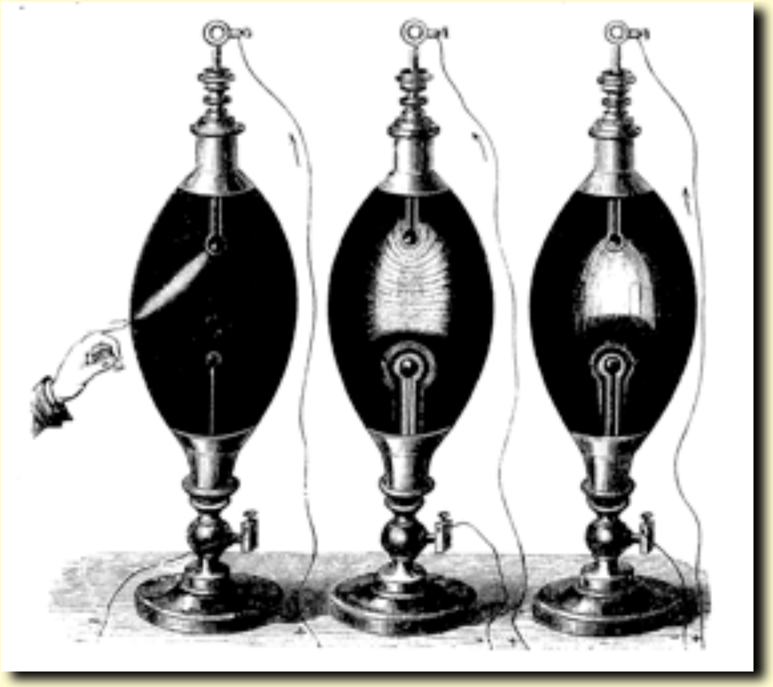


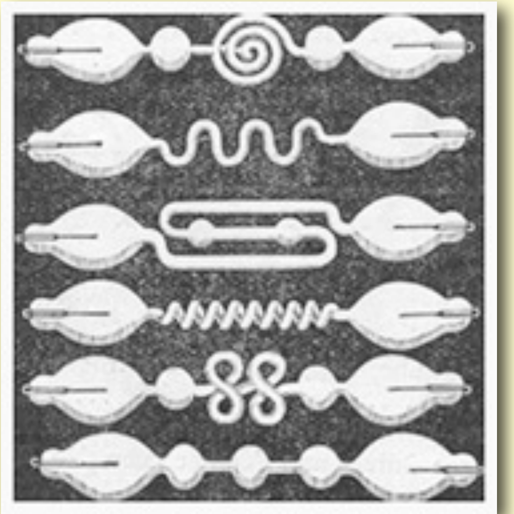
'fourth state
of matter'
(1879)

William Crookes

Cathode rays

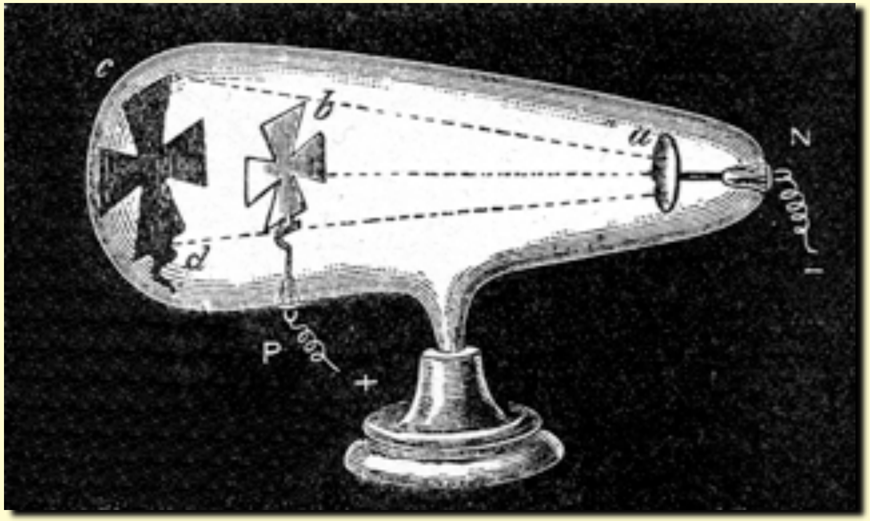


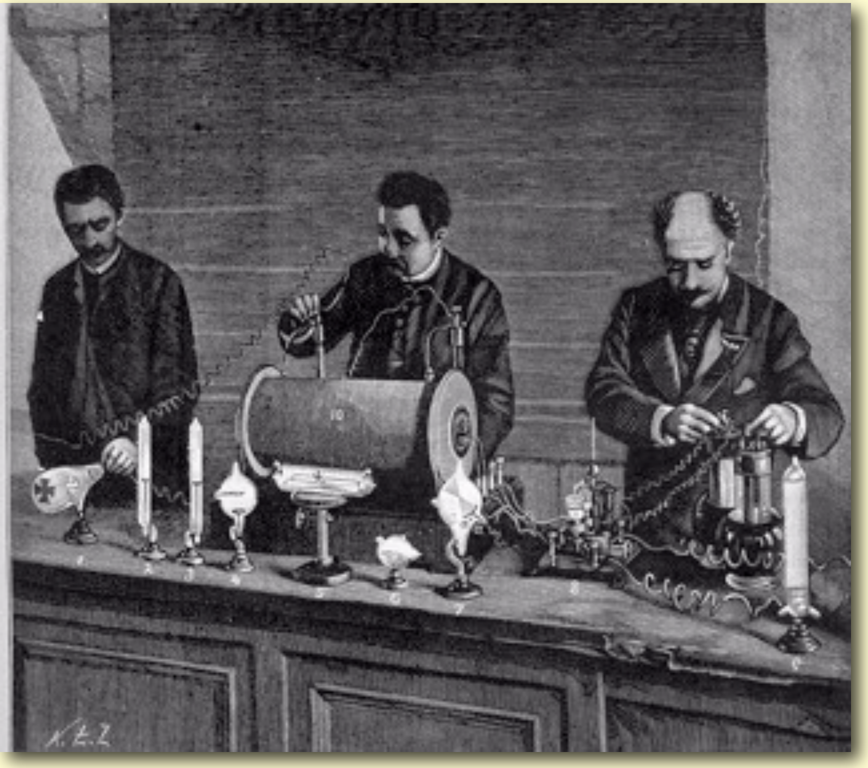


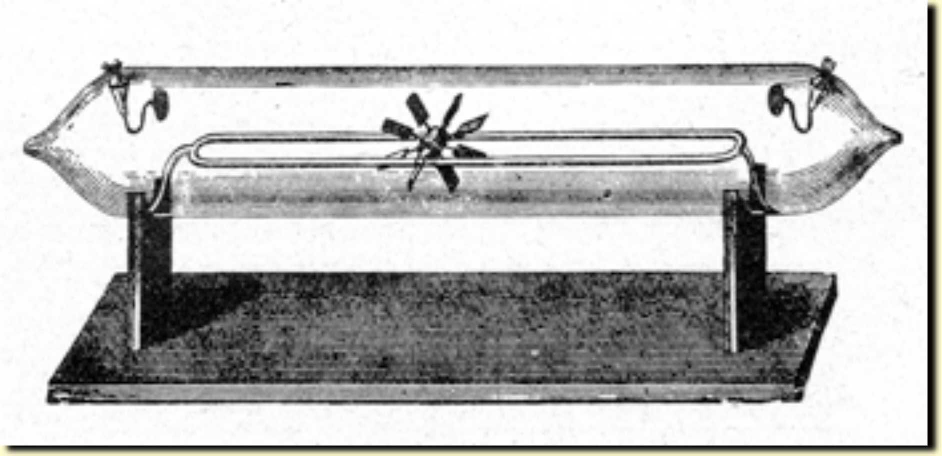


Geissler tubes

Cathode rays







Experiments with cathode rays (1892)

Aus den Sitzungsberichten der Würzburger Physik.-medic. Gesellschaft 1895.

W. C. Röntgen: Ueber eine neue Art von Strahlen.

(Vorläufige Mittheilung.)

1. Lässt man durch eine *Hittorf*'sche Vacuumröhre, oder einen genügend evacuirten *Lenard*'schen, *Crookes*'schen oder ähnlichen Apparat die Entladungen eines grösseren *Ruhmkorff*'s gehen und bedeckt die Röhre mit einem ziemlich eng anliegenden Mantel aus dünnem, schwarzem Carton, so sieht man in dem vollständig verdunkelten Zimmer einen in die Nähe des Apparates gebrachten, mit Bariumplatincyanür angestrichenen Papierschirm bei jeder Entladung hell aufleuchten, fluoresciren, gleichgültig ob die angestrichene oder die andere Seite des Schirmes dem Entladungsapparat zugewendet ist. Die Fluorescenz ist noch in 2 m Entfernung vom Apparat bemerkbar.

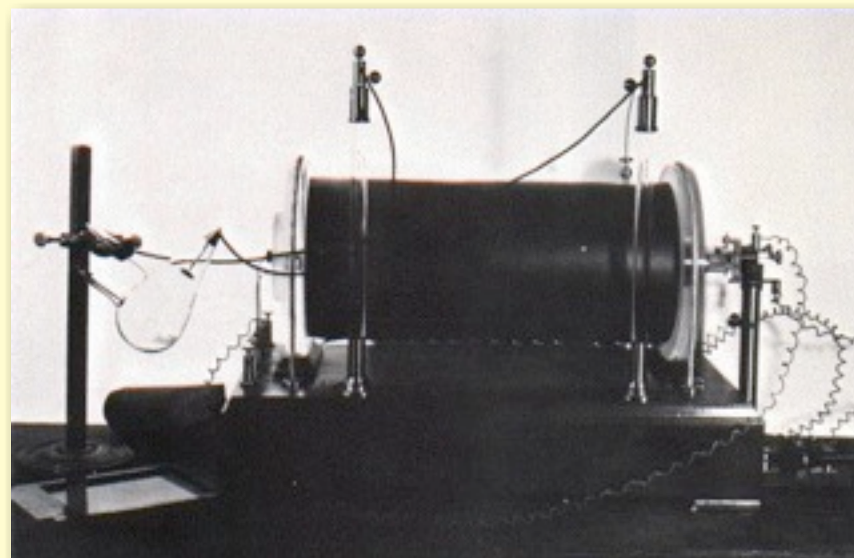
Man überzeugt sich leicht, dass die Ursache der Fluorescenz vom Entladungsapparat und von keiner anderen Stelle der Leitung ausgeht.

2. Das an dieser Erscheinung zunächst Auffallende ist, dass durch die schwarze Cartonhülse, welche keine sichtbaren oder ultravioletten Strahlen des Sonnen- oder des elektrischen Bogenlichtes durchlässt, ein Agens hindurchgeht, das im Stande ist, lebhafte Fluorescenz zu erzeugen, und man wird deshalb wohl zuerst untersuchen, ob auch andere Körper diese Eigenschaft besitzen.

Man findet bald, dass alle Körper für dasselbe durchlässig sind, aber in sehr verschiedenem Grade. Einige Beispiele führe ich an. Papier ist sehr durchlässig:[1]) hinter einem eingebundenen Buch von ca. 1000 Seiten sah ich den Fluorescenzschirm noch deutlich leuchten; die Druckerschwärze bietet kein merkliches Hinderniss. Ebenso zeigte sich Fluorescenz hinter einem doppelten Whistspiel; eine einzelne Karte zwischen Apparat

[1]) Mit „Durchlässigkeit" eines Körpers bezeichne ich das Verhältniss der Helligkeit eines dicht hinter dem Körper gehaltenen Fluorescenzschirmes zu derjenigen Helligkeit des Schirmes, welcher dieser unter denselben Verhältnissen aber ohne Zwischenschaltung des Körpers zeigt.

Wilhelm Conrad Röntgen
(1845-1923)



Early X-ray photographs

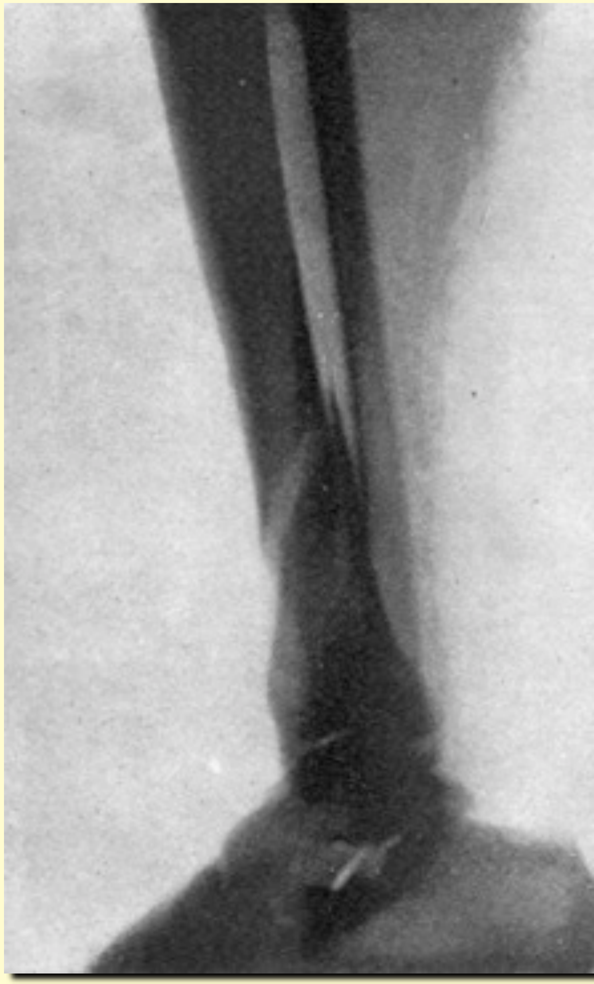
Bertha Röntgen
22 XII 1895

prof. A. von Kölliker
23 I 1896

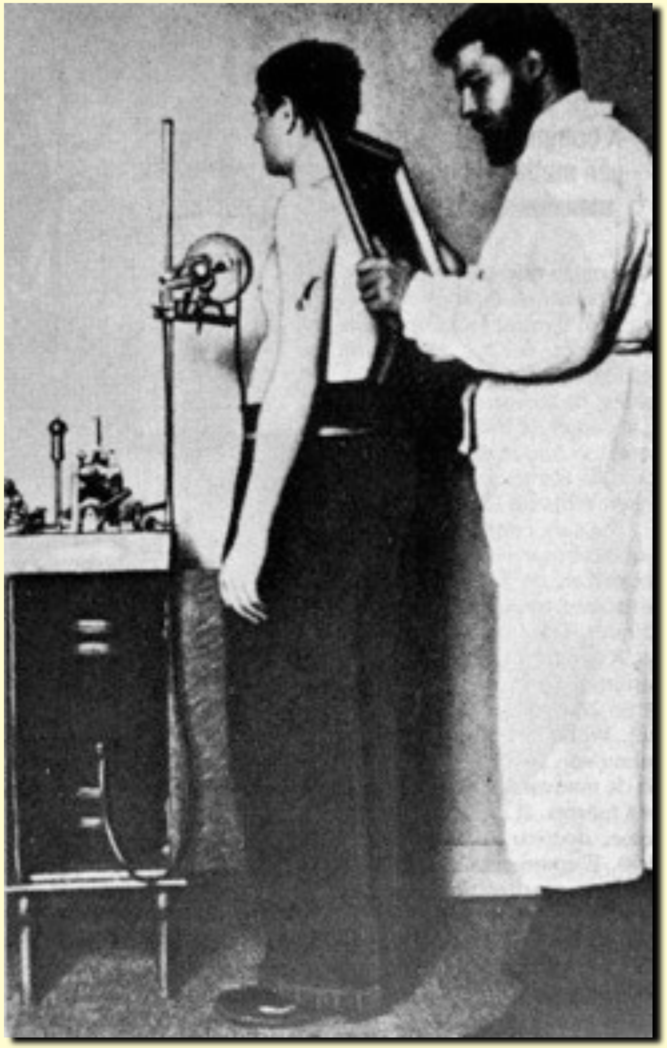
”...A kind of relationship between the new rays and light rays appears to exist; at least the formation of shadows, fluorescence and the production of chemical action point in this direction. Now it has been known for a long time, that besides the transverse vibrations which account for the phenomena of light, it is possible that longitudinal vibrations should exist in the ether, and, according to the view of some physicists, must exist. It is granted that their existence has not yet been made clear, and their properties are not experimentally demonstrated. Should not the new rays be ascribed to longitudinal waves in the ether?”

W. C. Röntgen, *Über eine neue Art von Strahlen* (December, 1895)

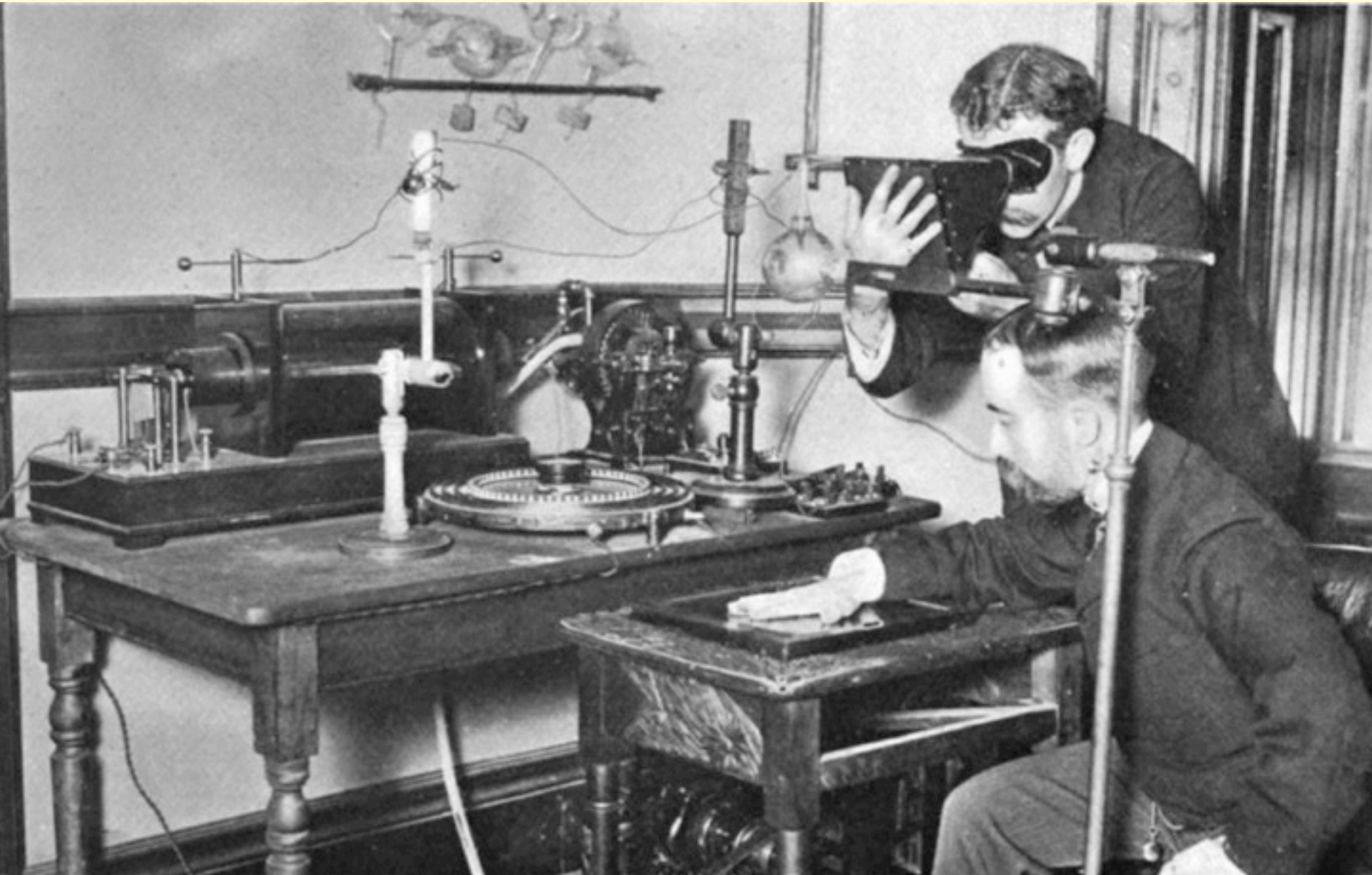
Early X-ray photographs



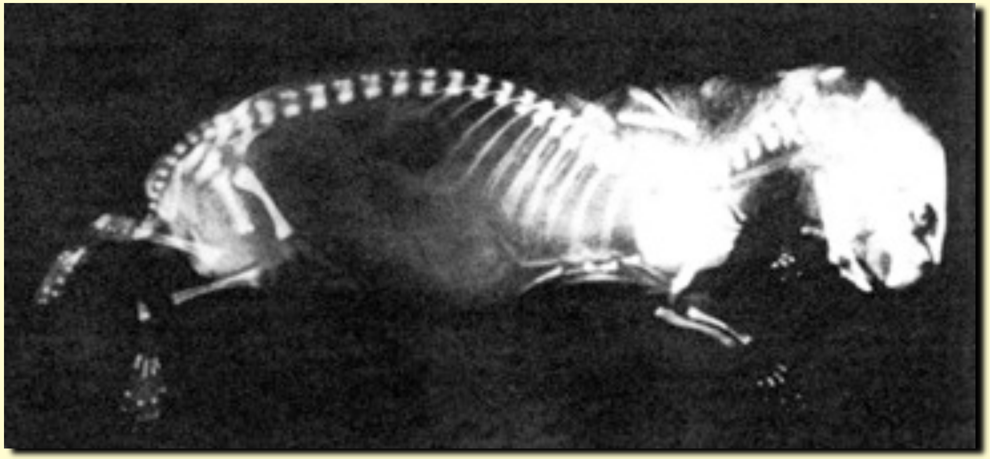
Early X-ray apparatus and photographs

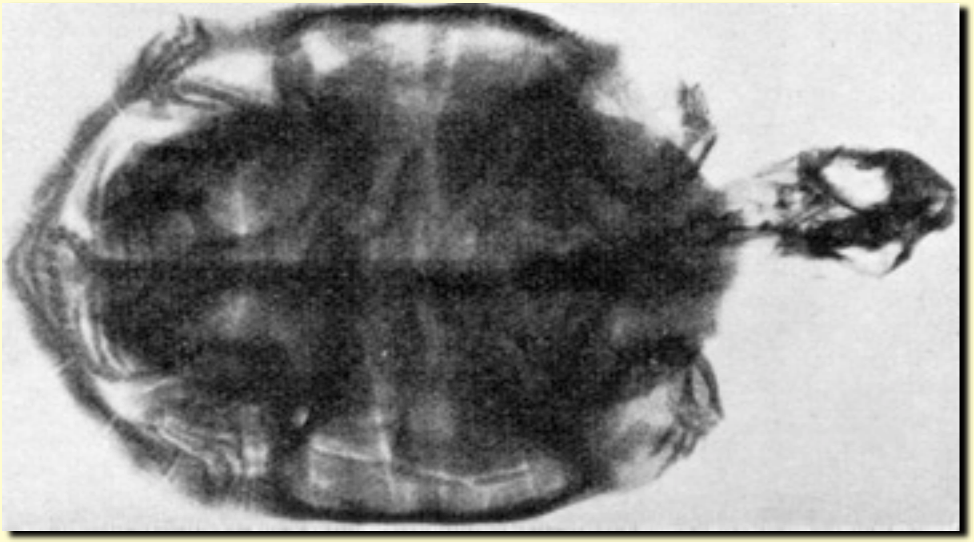


Early X-ray apparatus and photographs



Early X-ray photographs





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(5) Metal Objects inside a Wooden Box.
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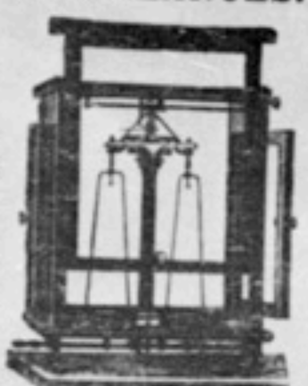

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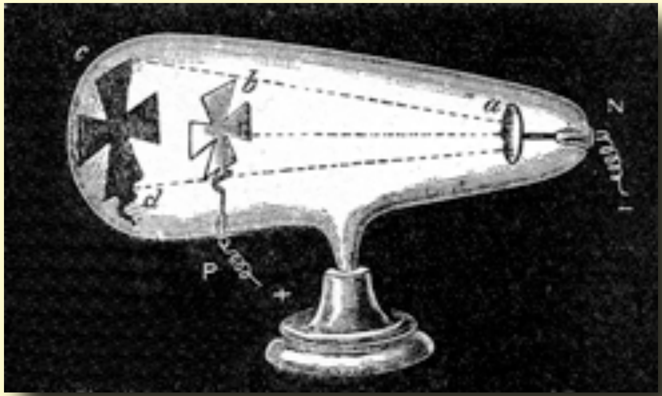
Discovery of radioactivity was an accidental consequence of the discovery of X-rays

Academy of Science meeting in Paris, January 20, 1896

Henri Poincaré:

”Emission of X rays may be connected with phosphorescence”



Accident no 1:
Becquerel picked up uranium-potassium sulphide out of his rich collection of phosphorescent minerals

Academy of Science meeting on February 24, 1896

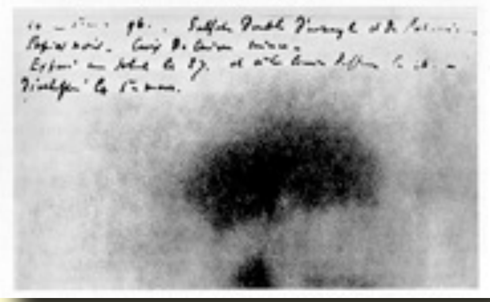
”Yes, my experiment confirmed Poincaré’s hypothesis”

Henri Becquerel

Accident no 2: weather in Paris deteriorated

”I particularly insist on the following fact, which appears to me exceedingly important and not in accord with the phenomena which one might expect to observe: the same encrusted crystals placed with respect to the photographic plates in the same conditions and acting through the same screens, but protected from the excitation of incident rays and kept in the dark, still produce the same photographic effects.
I may relate now how I was led to make this observation.”

Henri Becquerel

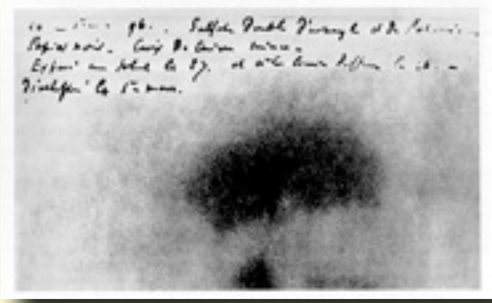


Academy of Science meeting on March 2, 1896

Accident no 2: weather in Paris deteriorated

"Among the preceding experiments some had been ready on Wednesday the 26th and Thursday the 27th of February and as on those days the sun only showed itself intermittently I kept my arrangements all prepared and put back the holders in the dark in the drawer of the case, and left in place the crusts of uranium salt. Since the sun did not show itself again for several days I developed the photographic plates on the 1th of March, expecting to find the images very feeble. The silhouettes appeared on the contrary with great intensity. I at once thought that the action might be able to go on in the dark."

Henri Becquerel



Academy of Science meeting on March 2, 1896

Why Becquerel went to his laboratory on Sunday morning (!) and decided to develop plates, although he knew that they had not been exposed to sunlight?

In 1867 Niépce de Saint Victor noticed that uranium salts cause ‘fogging’ of the photographic plates even when they are isolated from the salts by layers of paper

Did Becquerel know about it ???

Becquerel's reports to the Academy of Science in 1896

24 II	uranium emits radiation after exposure to light	**wrong**
2 III	uranium emits radiation by itself	**right**
9 III	intensity of uranium radiation unchanged after keeping it for a few days in darkness	**right**
	uranium radiation is reflected and refracted	**wrong**
23 III	intensity of uranium radiation is much larger than that of the Crookes' tube	**right**
30 III	uranium radiation undergoes double refraction in traversing a piece of tourmaline	**wrong**
23 V	radiation of metallic uranium is more intensive than that of its compounds	**right**

‘Discoveries’ of invisible penetrating radiation

27 I	Le Bon	‘black light’ (*lumiére noire)* from paraffin lamp
February	Mau	radiation from the sun
	Egbert	radiation from the sun
9 III	Troost	zinc sulphate
March	McKissick	various substances, e.g. ordinary chalk
March	Arnold	fluorite, mixtures of sulphates and tungstenites
11 V	Le Bon	‘black light’ may be concentrated by metals
6 VII	Colson	well polished zinc
13 VII	Pellat	steel
24 VIII	Henry	glow-worms (soon confirmed by Muraoka in Kyoto)

Becquerel decided to leave the field of radioactivity which seemed to be an ”uninteresting” problem
and for two years, until March 1899, studied only the Zeeman’s effect

“Since the discovery of the Röntgen Rays, Becquerel has discovered a new kind of light, which in its properties resembles the Röntgen rays more closely than any kind of light hitherto known...Becquerel has shown that the radiation from the uranium salts can be polarised, so that it is undoubtedly light; it can also be refracted. It forms a link between the Röntgen rays and ordinary light, it resembles the Röntgen rays in its photographic action, in power of penetrating substances opaque to ordinary light, and in the characteristic electrical effect, while it resembles ordinary light in its capacity for polarisation, in its liability to refraction... ”

J. J. Thomson, Rede Lecture “The Röntgen Rays”, Cambridge University, June 10, 1896

”The radiation from the uranium salts is of special interest from another point of view. Sir George Stokes has shown that in the case of phosphorescence caused by sunlight or the arc lamp, the light emitted by the phosphorescent body is of longer wave-length than the light causing the phosphorescence; in the case, however, of the phosphorescence discovered by Becquerel, the light emitted is of shorter wave-length than the incident light.”

J. J. Thomson, Rede Lecture “The Röntgen Rays”,
Cambridge University, June 10, 1896

Summary on the new rays in the middle of 1896 (unchanged until the spring of 1898)

Property	Röntgen rays	Uranium rays
Penetration through paper and aluminium	Yes	Yes
Penetration through heavier metals	No	No
Action on photographic plates	Yes	Yes
Ionization of air	Yes	Yes
Reflection	No	Yes*
Refraction	No	Yes*
Polarization	No	Yes*
Nature	**?**	**Very short ether waves**

* Erroneous Becquerel's results of March, 1896

"Becquerel rays occupy a unique position, inasmuch as far more is definitely known about them than any of the other 'new' "rays". With X-rays nothing has been proven one way or the other about their character, save that if they are ultra-violet rays their wave-length must be extremely small, so small that the refractive index for nearly all bodies is practically unity. With the rays of Becquerel there can be no reasonable doubt that they are short transverse ether waves."

Oscar M. Stewart, *Phys. Rev.* No. 4, April 1898

Summary on the new rays in the spring of 1898

Property	Röntgen rays	Uranium rays	Thorium rays
Penetration through paper and aluminium	Yes	Yes	Yes
Penetration through heavier metals	No	No	No
Action on photographic plates	Yes	Yes	Yes
Ionization of air	Yes	Yes	Yes
Reflection	No	Yes*	Yes (?)**
Refraction	No	Yes*	Yes**
Polarization	No	Yes*	No**
Nature	**?**	**Very short ether waves**	**?**

* Erroneous Becquerel's results of March, 1896

** Schmidt's results of February, 1898

Maria Skłodowska-Curie

Born in Warsaw on November 7, 1867 in this house at 16, Freta Street

A few facts about the first steps of Maria Skłodowska-Curie

1883 graduated from a high school in Warsaw (first place)

1891 in November left for Paris (with a Russian passport)

1893 July 28, graduated as "*licenciée des sciences physiques*" (first in a class of thirty)

1894 **July 28, graduated** as "*licenciée des sciences mathématiques*" (second in her class)

1895 July 26, marriage with Pierre Curie (became French citizen)

1896 August 15, came out first in the examination for teachers;

undertook a study of magnetic properties of tempered steel

Maria Skłodowska-Curie

12 August 1897 – daughter Irène is born

7 November 1897 – Maria is 30 years of age

27 December 1897 – first publication (on tempered steel)

> ”I had decided on a theme of my doctorate. My attention had been drawn to the interesting experiments of Henri Becquerel on the salts of the rare metal uranium.”
> Maria Skłodowska-Curie - *Autobiographical Notes*

12 April 1898 – publication of the ground-breaking article

PHYSIQUE. — *Rayons émis par les composés de l'uranium et du thorium.* Note de Mme SKLODOWSKA CURIE (1), présentée par M. Lippmann.

18 June 1898 – discovery of polonium

26 December 1898 – discovery of radium

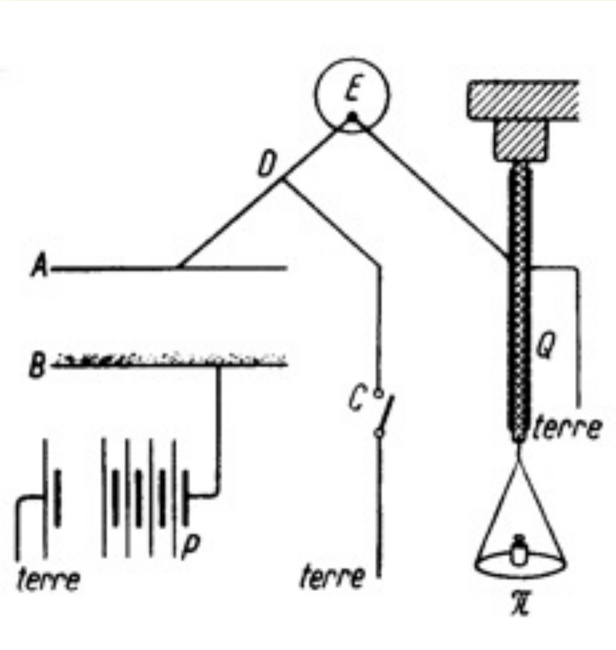
Maria Skłodowska-Curie, April 12, 1898

PHYSIQUE. — *Rayons émis par les composés de l'uranium et du thorium.* Note de M^me^ SKLODOWSKA CURIE [1], présentée par M. Lippmann.

"I have studied the conductivity of air under the influence of the rays from uranium, discovered by Mr. Becquerel, and I have sought whether any other bodies than those composed of uranium are able to render air a conductor of electricity."

PHYSIQUE. — *Rayons émis par les composés de l'uranium et du thorium.* Note de Mme Sklodowska Curie [1], présentée par M. Lippmann.

"I used for this study a plate condenser; one of the plates was covered with a uniform layer of uranium or another substance pulverised.
A difference of potential of 100 Volts was established between the plates.
The current, which passed through the condenser, was measured in absolute value by means of an electrometer and a piezo-electric quartz."



PHYSIQUE. — *Rayons émis par les composés de l'uranium et du thorium.* Note de Mme SKLODOWSKA CURIE (1), présentée par M. Lippmann.

"I have examined a great number of metals, salts, oxides and minerals...All the compounds of uranium studied are very active and they are, in general, the more active the more uranium they contain.
The compounds of thorium are very active. The oxide of thorium even exceeds metallic uranium in activity.
It should be noted that two most active elements, uranium and thorium, are those which have the greatest atomic weight."

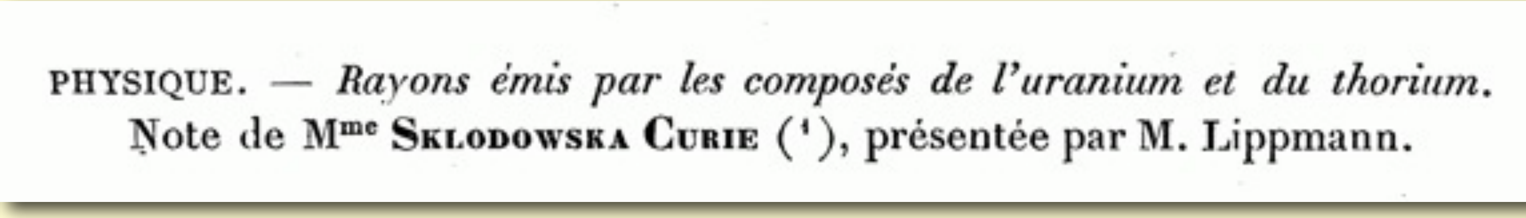
Maria Skłodowska-Curie, April 12, 1898

PHYSIQUE. — *Rayons émis par les composés de l'uranium et du thorium.* Note de Mme SKLODOWSKA CURIE [1], présentée par M. Lippmann.

"Two ores of uranium, pitchblende (uranium oxide) and chalcolite (phosphate of copper and uranium) are much more active than uranium itself. **This fact is very remarkable and leads to the belief that these minerals may contain an element much more active than uranium...**

I have produced chalcolite by the process of Debray from pure materials, this artificial chalcolite is no more active than any other salt of uranium."

Maria Skłodowska-Curie, April 12, 1898


PHYSIQUE. — *Rayons émis par les composés de l'uranium et du thorium.* Note de M[me] Sklodowska Curie ([1]), présentée par M. Lippmann.

"To interpret the spontaneous radiation of uranium and thorium one might imagine that all space is constantly traversed by rays analogous to Röntgen rays but much more penetrating and able to be absorbed only by certain elements of high atomic weight, such as uranium and thorium."

Maria Skłodowska-Curie, April 12, 1898

Synopsis of the paper of April 12, 1898

- Good quantitative method of detection
- Large number of investigated substances
- Discovery of thorium radiation
- Intensity of radiation in general found proportional to the contents of uranium in various minerals
- Radiation is an atomic property of uranium
- Chalcolite and pitchblende radiation stronger than uranium
- Synthesis of chalcolite from its components
- Bold hypothesis about the existence of a new strongly radioactive chemical element
- Analysis of absorption of uranium and thorium radiation
- Comparison of the effects of uranium and thorium radiation with that of Röntgen rays
- Bold hypothesis about possible source of energy of uranium and thorium radiation

Maria Skłodowska-Curie and others

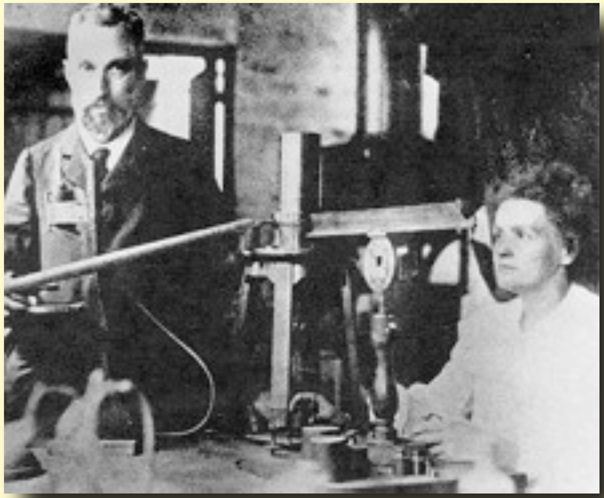
Emilio Villari studied the discharge of an electroscope by uranite (same as pitchblende!) – he did not think about quantitative measurements

Gerhardt Schmidt did not attempt measurements of the intensity of radiation of various minerals containing uranium – he obviously considered it to be a loss of time

Maria Skłodowska-Curie made a great discovery by looking for answers to very simple questions

”It appeared that the results of my work were so interesting that Monsieur Curie interrupted his crystallographic work and joined me to take part in the experiments. Since then we worked together trying to extract and investigate new radioactive bodies.”

Maria Skłodowska-Curie,
Ph.D. Thesis (1903)



Discovery of polonium (July 18, 1898)

"Certain minerals containing uranium and thorium (pitchblende, chalcolite, uranite) are very active from the point of view of emission of Becquerel rays. In earlier work, one of us has shown that their activity is even greater than that of uranium and thorium, and has made the statement that this effect must be due to some other very active substance contained in a very small quantity in these minerals...

We believe therefore that the substance, which we have recovered from pitchblende contains a metal not yet described, related to bismuth in its analytical properties. If the existence of this new metal is confirmed, we propose to call it polonium, after the native country of one of us."

» En effectuant ces diverses opérations, on obtient des produits de plus en plus actifs. Finalement nous avons obtenu une substance dont l'activité est environ 400 fois plus grande que celle de l'uranium.

» Nous avons recherché, parmi les corps actuellement connus, s'il en est d'actifs. Nous avons examiné des composés de presque tous les corps simples; grâce à la grande obligeance de plusieurs chimistes, nous avons eu des échantillons des substances les plus rares. L'uranium et le thorium sont seuls franchement actifs, le tantale l'est peut-être très faiblement.

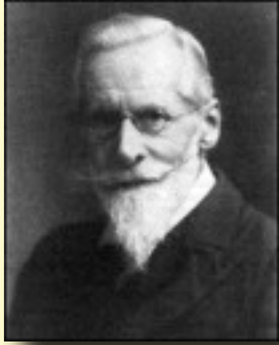
» Nous croyons donc que la substance que nous avons retirée de la pechblende contient un métal non encore signalé, voisin du bismuth par ses propriétés analytiques. Si l'existence de ce nouveau métal se confirme, nous proposons de l'appeler *polonium*, du nom du pays d'origine de l'un de nous.

Nature, 28 VI 1898

—On a new radio-active substance contained in pitchblende, by M. P. Curie and Mme. S. Curie. Previous researches have shown that the activity of the Becquerel rays emitted by uranium compounds is proportional to the amount of the metal present. This, however, is not the case for pitchblende, in which the activity is much greater than that calculated from its percentage of uranium. Hence arose the possibility of the presence of a new substance, to account for the increased activity. In the separation of the metals as sulphides the active material was thrown down along with bismuth sulphide; a partial separation could be effected by heating in vacuo at 700° C., the sublimate thus obtained possessing 400 times the activity of uranium. Since no chemical substance out of a large number examined behaves in a similar manner, the authors believe the metal to be a new one, and suggest the name of *polonium*, from the country in which the pitchblende was found. The spectrum exhibits no characteristic ray.

”Quite recently M. and Mdme. Curie have announced a discovery which, if confirmed, cannot fail to assist the investigation of this obscure branch of physics. They have brought to notice a new constituent of uranium mineral pitchblende, which in a 400-fold degree possesses uranium’s mysterious power of emitting a form of energy capable of impressing a photographic plate and of discharging electricity by rendering air a conductor. It also appears that the radiant activity of the new body, to which the discoverers have given the name of Polonium, needs neither the excitation of light nor the stimulus of electricity; like uranium, it draws its energy from some constantly regenerating and hitherto unsuspected store, exhaustless in amount...”

William Crookes, September 1898



"The reduction of the speed of the quick moving molecules would cool the layer of air to which they belong; but this cooling would rapidly be compensated by radiation and conduction from the surrounding atmosphere; under ordinary circumstances the difference of temperature would scarcely be perceptible, and the uranium would thus appear to perpetually emit rays of energy with no apparent means of restoration.

The total energy of both the translational and internal motions of the molecules locked up in quiescent air at ordinary pressure and temperature is about 140000 foot-pounds in each cubic yard of air. Accordingly the quiet air within a room 12 feet high, 18 feet wide, and 22 feet long contains energy enough to propel a one-horse engine by more than twelve hours. The store drawn upon naturally by uranium and other heavy atoms only awaits the touch of the magic wand of science to enable the twentieth century to cast into the shade the marvels of the nineteenth."

William Crookes, September 1898

“All the results that have been obtained point to the conclusion that uranium gives out types of radiation which, as regards their effect on gases, are similar to Röntgen rays and the secondary radiation emitted by metals when Röntgen rays fall upon them.
If there is no polarisation or refraction the similarity is complete...

It is possible that the apparently very powerful radiation obtained from pitchblende by Curie may be partly due to the very fine state of division of the substance rather than to the presence of a new and powerful radiating substance.”

Ernest Rutherford, *Phil. Mag.* 47, 109, January 1899

Discovery of radium (December 26,1898)

”The different reasons which we have enumerated lead us to believe that the new radio-active substance contains a new element to which we propose to give the name of radium... The new radio-active substance certainly contains a very great proportion of barium; in spite of that, the radioactivity is considerable. The radio-activity of radium must therefore be enormous...”

M. Skłodowska-Curie, *Rev. Gen. des Sciences* (January 1899)

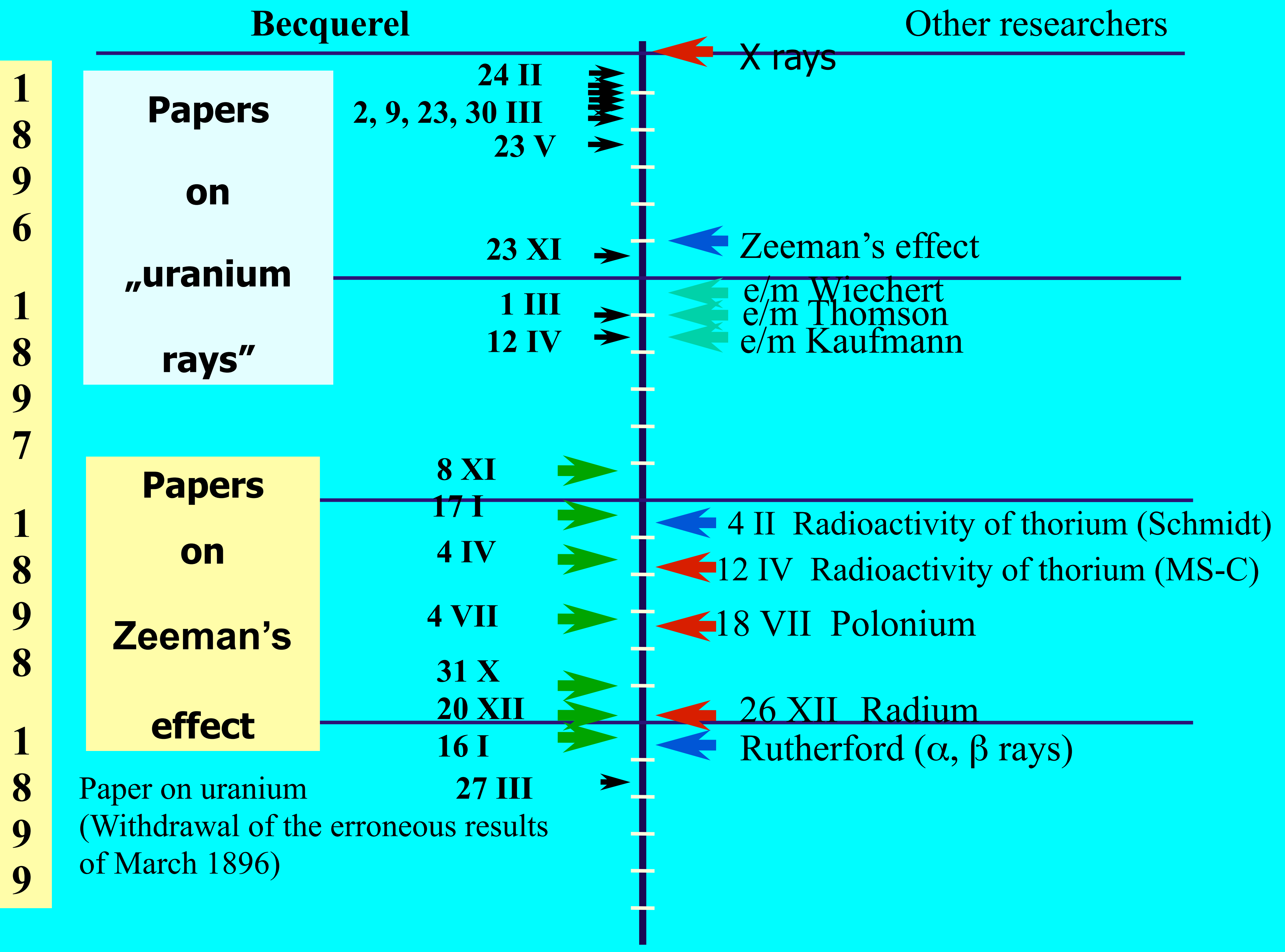
First hypotheses concerning the source of energy of radioactive elements:

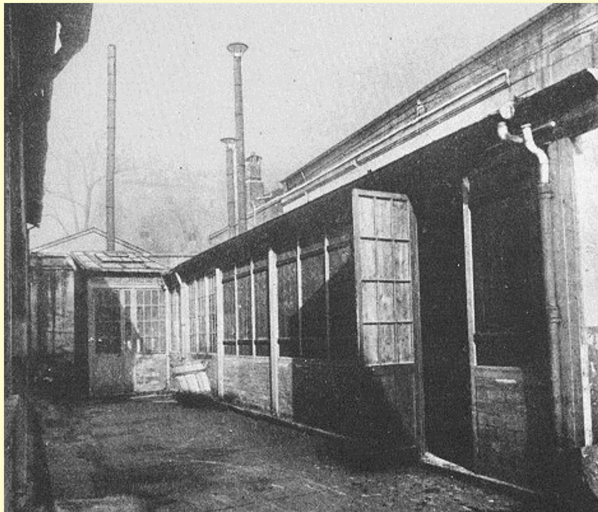
- A kind of phosphorescence with very long decay time (an improbable hypothesis)
- Emission of matter accompanied by a loss of mass of radioactive substances
- Energy of radioactive bodies continuously decreases; this hypothesis could be connected with Crookes' ideas on the evolution of elements
- Heavy atoms have the property of absorption of energy from outside sources and its emission in a form of penetrating radiation

Becquerel, full of shame and chagrin, returned to his experiments and soon retracted erronenous results which he published in March, 1896.

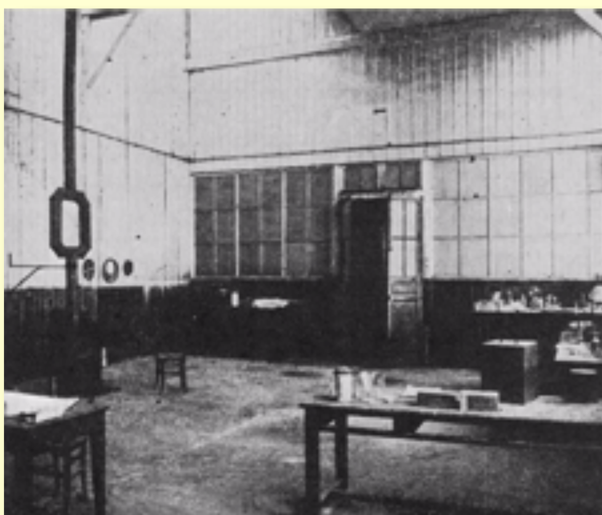
He tried to make up for lost time and very frequently visited Curie's laboratory,

In March 1902 Pierre Curie wrote to his friend Georges Gouy that ”...*Becquerel is most obtrusive, we have him constantly breathing down our necks”*


Becquerel
Other researchers
X rays
1896
Papers on „uranium rays"
24 II
2, 9, 23, 30 III
23 V
23 XI
Zeeman's effect
1897
1 III
12 IV
e/m Wiechert
e/m Thomson
e/m Kaufmann
8 XI
1898
Papers on Zeeman's effect
17 I
4 II Radioactivity of thorium (Schmidt)
4 IV
12 IV Radioactivity of thorium (MS-C)
4 VII
18 VII Polonium
31 X
20 XII
26 XII Radium
1899
16 I
Rutherford (α, β rays)
Paper on uranium
27 III
(Withdrawal of the erroneous results of March 1896)



The Curie's laboratory in which polonium and radium have been discovered



Summary on the new rays in the spring of 1899

Property	Röntgen rays	uranium, thorium, polonium, radium rays
Penetration through paper and aluminium	Yes	Yes
Penetration through heavier metals	No	No
Action on photographic plates	Yes	Yes
Ionization of air	Yes	Yes
Reflection	No	No
Refraction	No	No
Polarization	No	No
Nature	**?**	**?**

Hypotheses concerning the source of energy of the radioactive elements:

Their heavy atoms can absorb energy from external sources

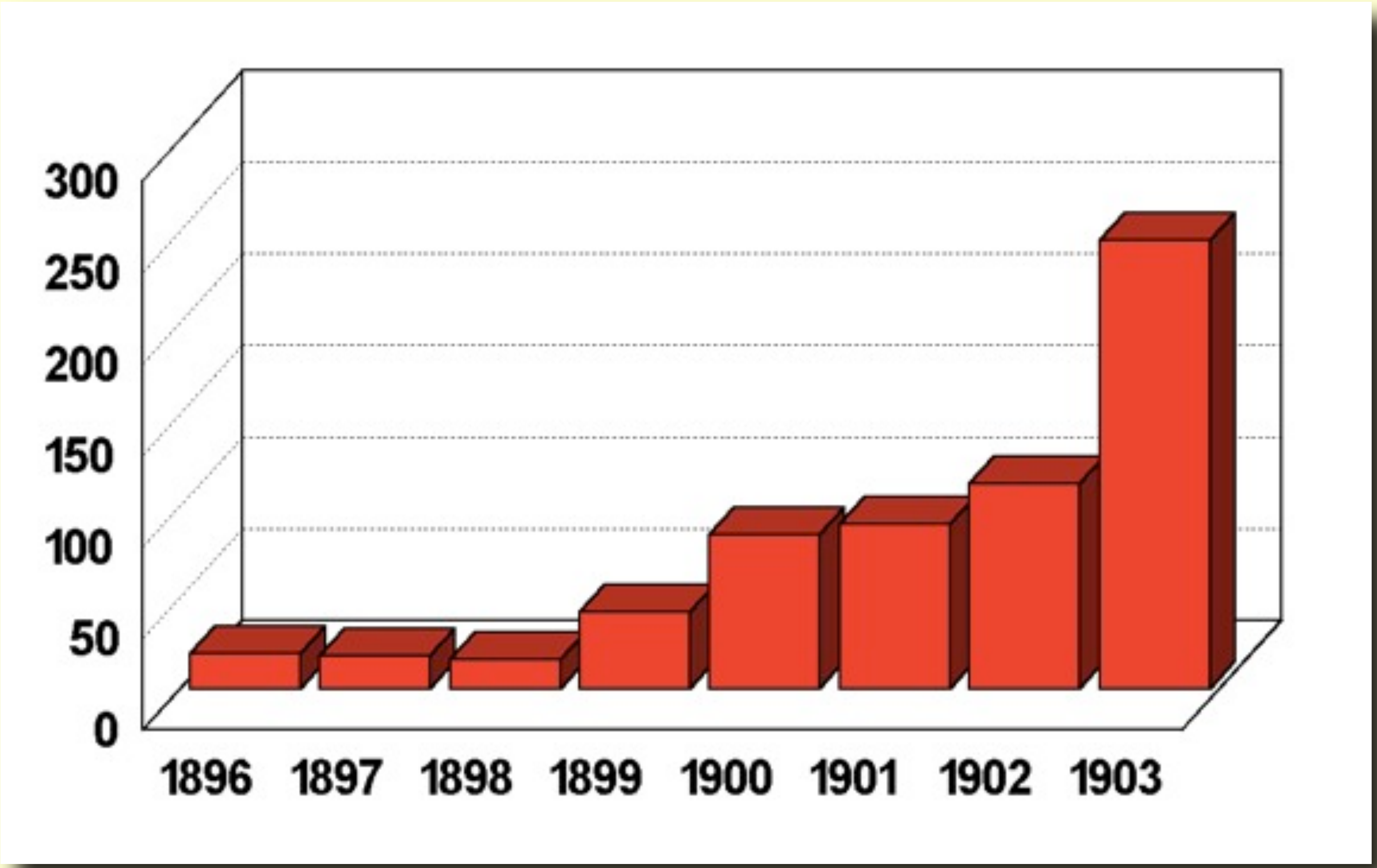
- **the fastest gas particles**
  - **- Crookes (1898)**
- **invisible radiation which fills the universe**
  - **- M. Curie (1898), P. Curie (1903), Mendelejew (1903), Kelvin (1905)**

and its emission in the form of a penetrating radiation

“In early 1898, radioactivity was something of a ‘dead horse’ - it was there, but no one knew what to do with it. It took not only the discovery of thorium’s activity, first by Gerhard C. Schmidt and then by Marie Curie, but the subsequent discoveries of polonium and radium by the Curies to produce a sustained renewal of interest. For then it became apparent that this was an atomic phenomenon of great significance.”

Lawrence Badash
(1965)

Papers on radioactivity



{based on Max Iklé, *Jahrbuch der Radioaktivität und Elektronik*, 1, 413-442 (1904)}

1899 Rutherford — the two components α, β, of uranium radiation differ in ability of penetrating matter

1899 Geisel, Meyer, Schweidler — uranium rays deflected in a magnetic field

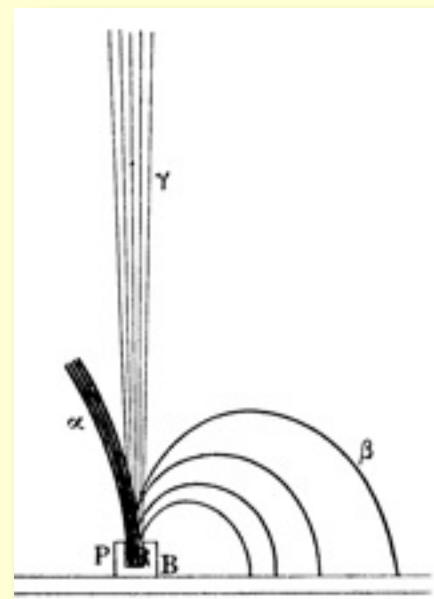
1900 Villard — discovery of γ rays, which are not deflected in a magnetic field

1900 Dorn — deviation of beta rays in an electric field

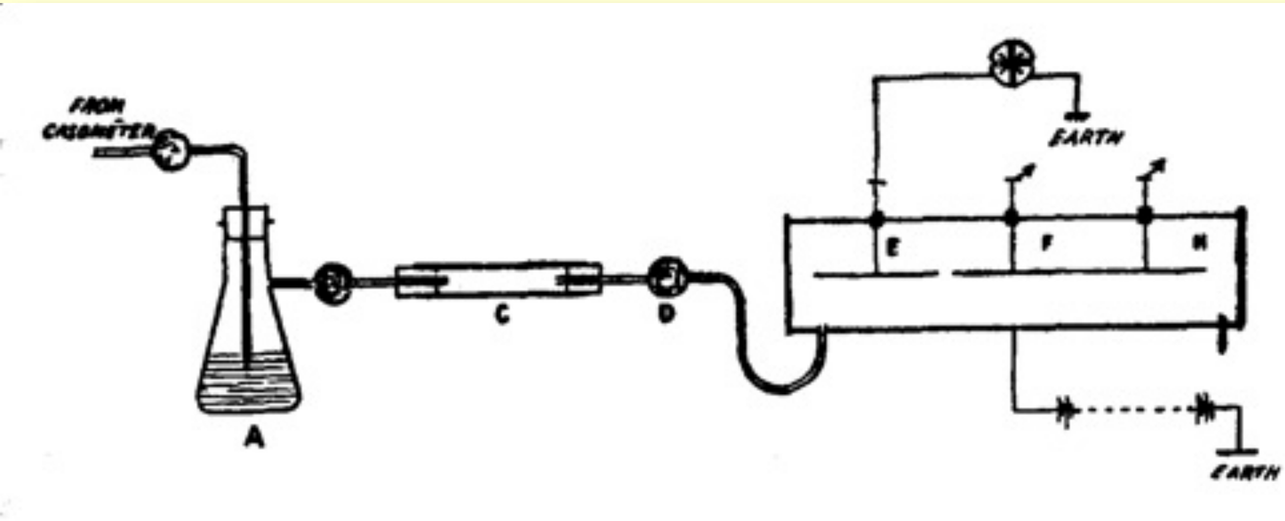
1900 Rutherford — radiation of thorium emanation decreases exponentially with time as $I = I_o \exp(-\lambda t)$

1902 Rutherford, Soddy — theory of radioactive transformations

Paul Villard

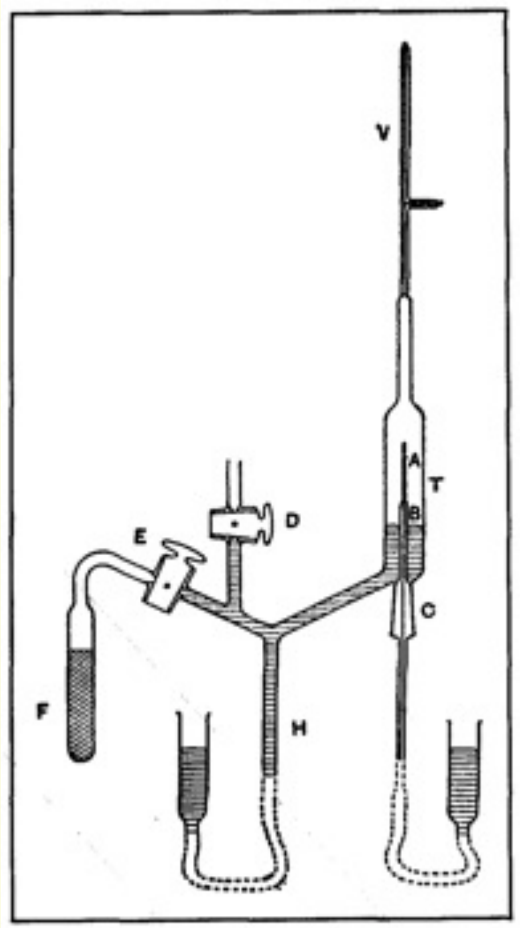


Maria Curie drawing (1903)



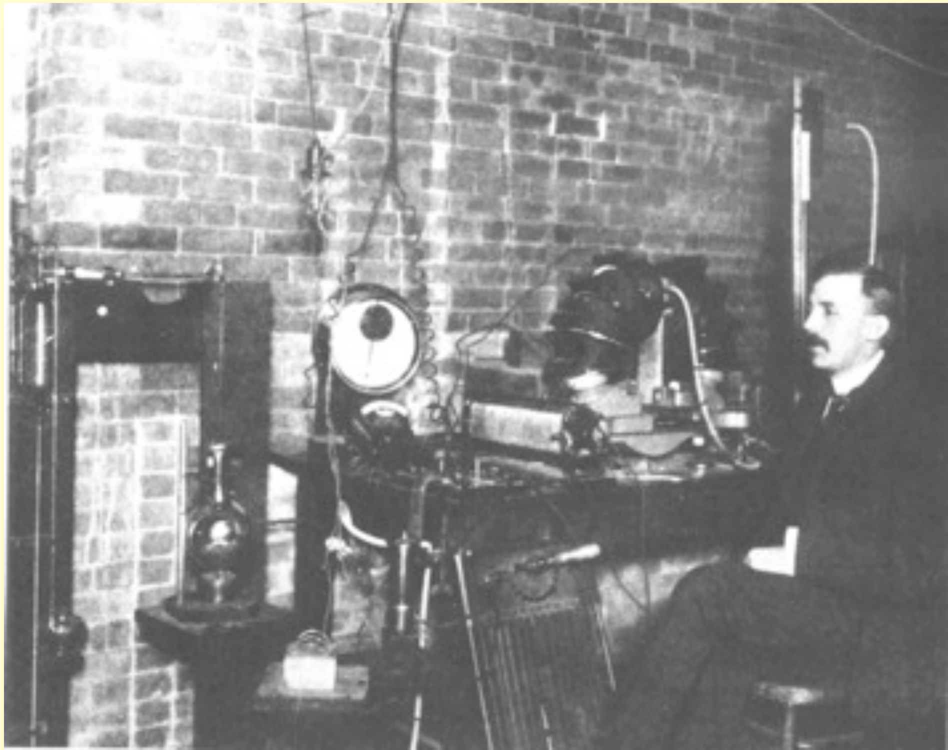
Rutherford and Soddy (1902)
Measurement of the life-time of thorium emanation

Frederic Soddy



Alpha particles
are ionized helium
(1908)

Hans Geiger (1882-1945) and
Ernest Rutherford (1871-1937)
in Manchester (1908)



From the cathode rays
to
the electron

”J. J. Thomson discovered the electron. Numerous are the books and articles in which one finds it said he did so in 1897. I cannot quite agree.”

Abraham Pais - *Inward Bound*

”It is often said that the electron was discovered shortly before the turn of the century by J. J. Thomson. That is an oversimplification."

Hendrik Casimir - *Haphazard Reality*

Who discovered the electron ?

1871	Varley	cathode rays are corpuscles
1874	Stoney	first estimate of elementary charge
1881	Helmholtz	”atoms of electricity”
1891	Stoney	term ”electron” coined
1892	Lorentz	electron theory of matter
		(1892 charged particles, 1895 ions,1899 electrons)
XI 1896	Lorentz	e/m for ”electrons” from Zeeman effect
I 1897	Wiechert	e/m for cathode rays (perhaps Helmholtz atoms)
IV 1897	Kaufmann	e/m for cathode rays (not corpuscles)
IV 1897	Thomson	e/m for cathode rays (corpuscles)

Who discovered the electron ?

1871	Varley	cathode rays are corpuscles
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IV 1897	Thomson	e/m for cathode rays (corpuscles)

1899 Lorentz electrons = cathode rays = beta rays

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

OCTOBER 1897.

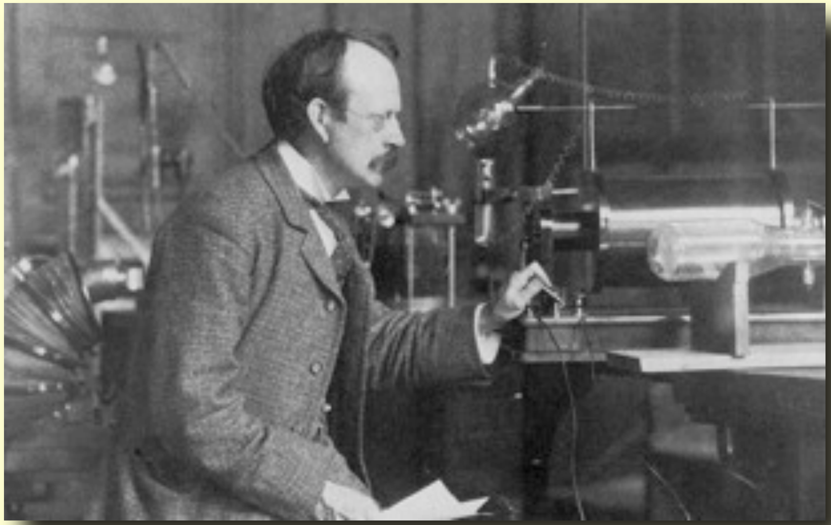
XL. *Cathode Rays.* By J. J. Thomson, *M.A., F.R.S., Cavendish Professor of Experimental Physics, Cambridge**.

THE experiments† discussed in this paper were undertaken in the hope of gaining some information as to the nature of the Cathode Rays. The most diverse opinions are held as to these rays; according to the almost unanimous opinion of German physicists they are due to some process in the æther to which—inasmuch as in a uniform magnetic field their course is circular and not rectilinear—no phenomenon hitherto observed is analogous: another view of these rays is that, so far from being wholly ætherial, they are in fact wholly material, and that they mark the paths of particles of matter charged with negative electricity. It would seem at first sight that it ought not to be difficult to discriminate between views so different, yet experience shows that this is not the case, as amongst the physicists who have most deeply studied the subject can be found supporters of either theory.

The electrified-particle theory has for purposes of research a great advantage over the ætherial theory, since it is definite and its consequences can be predicted; with the ætherial theory it is impossible to predict what will happen under any given circumstances, as on this theory we are dealing with hitherto

* Communicated by the Author.

† Some of these experiments have already been described in a paper read before the Cambridge Philosophical Society (Proceedings, vol. ix. 1897), and in a Friday Evening Discourse at the Royal Institution ('Electrician,' May 21, 1897).



J. J. Thomson studying the cathode rays

“The experiments discussed in this paper were undertaken in the hope of gaining some information as to the nature of the Cathode Rays. The most diverse opinions are held as to these rays; according to the almost unanimous opinion of German physicists they are due to some process in the aether to which - inasmuch as in a uniform magnetic field their course is circular and not rectilinear - no phenomenon hitherto observed is analogous: another view of these rays is that, so far from being wholly aetherial, they are in fact wholly material, and that they mark the paths of particles of matter charged with negative electricity. It would seem at first sight that it ought not to be difficult to discriminate between views so different, yet experience shows that this is not the case, as amongst the physicists who have most deeply studied the subject can be found supporters of either theory.

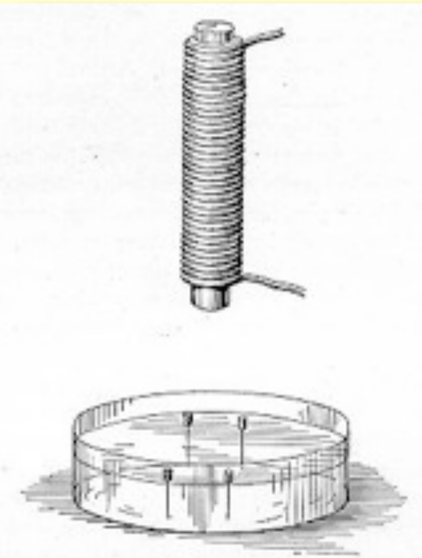
The electrified-particle theory has for purposes of research a great advantage over the aetherial theory, since it is definite and its consequences can be predicted; with the aetherial theory it is impossible to predict what will happen under any given circumstances, as on this theory we are dealing with hitherto unobserved phenomena in the aether, of whose laws we are ignorant.“

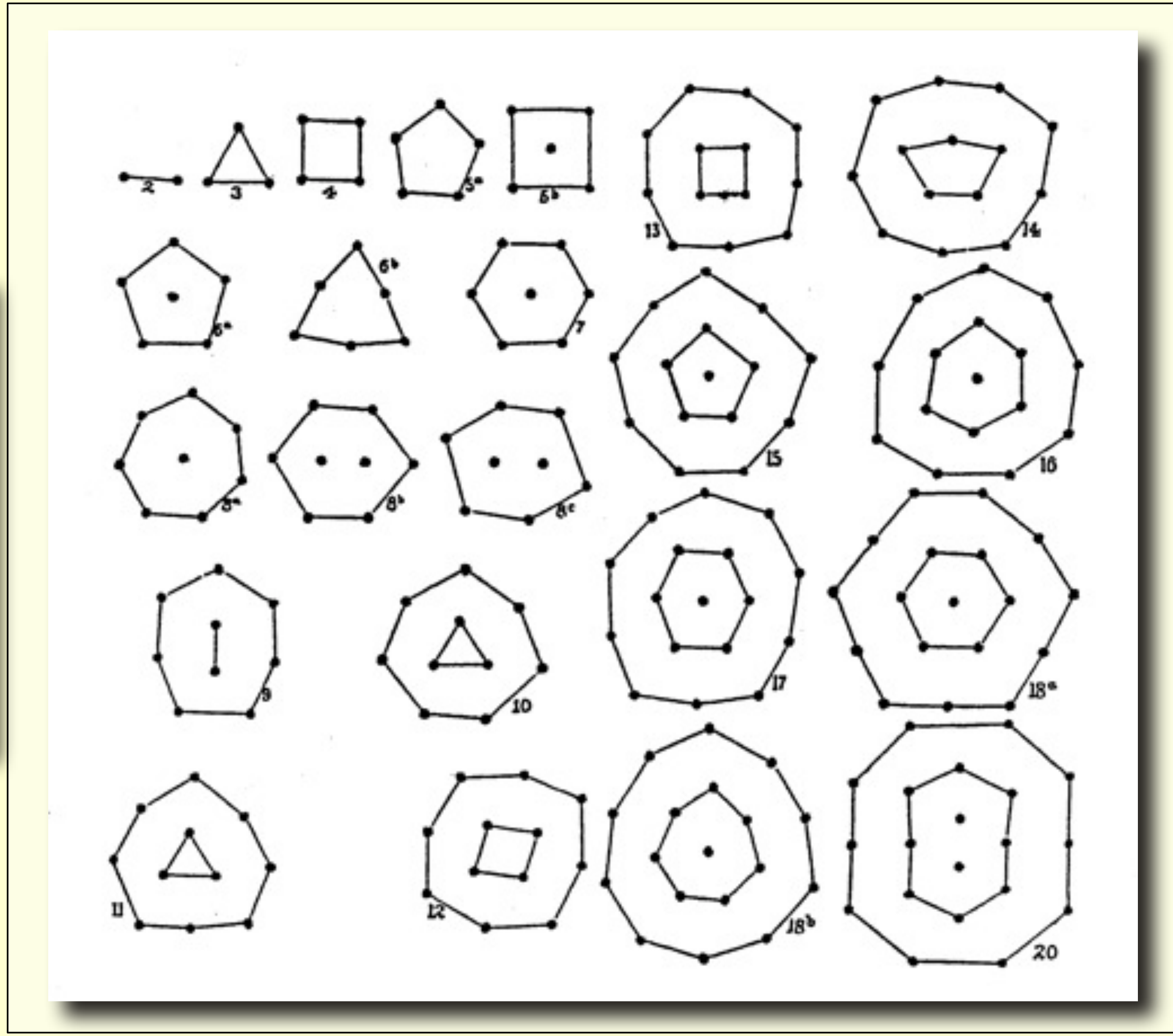
”I regard the atom as containing a large number of small bodies which I shall call corpuscles; these corpuscles are equal to each other; the mass of the corpuscle is the mass of a negative ion in a gas at low pressure, i.e. about 3×10^{-26} of a gramme. In the normal atom, this assemblage of corpuscles forms a system which is electrically neutral.”

"Among the branches of physical investigation that have recently shown especial activity, few occupy a more prominent position at the present time than those that are related to the electrical discharge in rarefied gases. This is true not only because of the rapid development of the subject, but also because of the far reaching importance of the results, and the influence which they seem destined to exert upon widely different branches of physics...

The most serious reason for doubting the correctness of the values obtained for e/m ratio arises from the almost incredible velocity of the kathode rays. What right have we to suppose that ordinary electrical and mechanical laws are applicable to a particle moving at one-third the velocity of light? It appears to me that we have before us the most stupendous piece of extrapolation in the whole history of physics."

Ernest Merritt (Cornell): Address of the Vice-president of the American Association for the Advancement of Science at the New York meeting (1900).
Science, XII, No. 289, July 13, 1900.





A. Mayer, *Am. Journ. Sci.*, **116**, 248 (1878)

no longer holds: thus 6 magnets do not arrange themselves at the corners of a hexagon, but divide into two systems, consisting of 1 in the middle surrounded by 5 at the corners of a pentagon. For 8 we have two in the inside and 6 outside; this arrangement in two systems, an inner and an outer, lasts up to 18 magnets. After this we have three systems: an inner, a middle, and an outer; for a still larger number of magnets we have four systems, and so on.

Mayer found the arrangement of magnets was as follows:—

1.	2.	3.	4.	5.
1 . 5 1 . 6 1 . 7	2 . 6 2 . 7	3 . 7 3 . 8	4 . 8 4 . 9	5 . 9
1 . 5 . 9 1 . 6 . 9 1 . 6 . 10 1 . 6 . 11	2 . 7 . 10 2 . 8 . 10 2 . 7 . 11	3 . 7 . 10 3 . 7 . 11 3 . 8 . 10 3 . 8 . 11 3 . 8 . 12 3 . 8 . 13	4 . 8 . 12 4 . 8 . 13 4 . 9 . 12 4 . 9 . 13	5 . 9 . 12 5 . 9 . 13
1 . 5 . 9 . 12 1 . 5 . 9 . 13 1 . 6 . 9 . 12 1 . 6 . 10 . 12 1 . 6 . 10 . 13 1 . 6 . 11 . 12 1 . 6 . 11 . 13 1 . 6 . 11 . 14 1 . 6 . 11 . 15 1 . 7 . 12 . 14	2 . 7 . 10 . 15 2 . 7 . 12 . 14	3 . 7 . 12 . 13 3 . 7 . 12 . 14 3 . 7 . 13 . 14 3 . 7 . 13 . 15	4 . 9 . 13 . 14 4 . 9 . 13 . 15 4 . 9 . 14 . 15	

where, for example, 1 . 6 . 10 . 12 means an arrangement with one magnet in the middle, then a ring of six, then a ring of ten, and a ring of twelve outside.

Now suppose that a certain property is associated with two magnets forming a group by themselves; we should have this property with 2 magnets, again with 8 and 9, again with 19 and 20, and again with 34, 35, and so on. If we regard the system of magnets as a model of an atom, the number of magnets being proportional to the atomic weight, we should have this property occurring in elements of atomic weight 2, (8, 9), 19, 20, (34, 35). Again, any property conferred by three magnets forming a system by themselves would occur with atomic weights 3, 10, and 11; 20, 21, 22, 23, and 24; 35, 36, 37 and 39; in fact, we should have something quite analogous to the periodic law, the first series corresponding to the arrangement of the magnets in a single group, the second series to the arrangement in two groups, the third series in three groups, and so on.

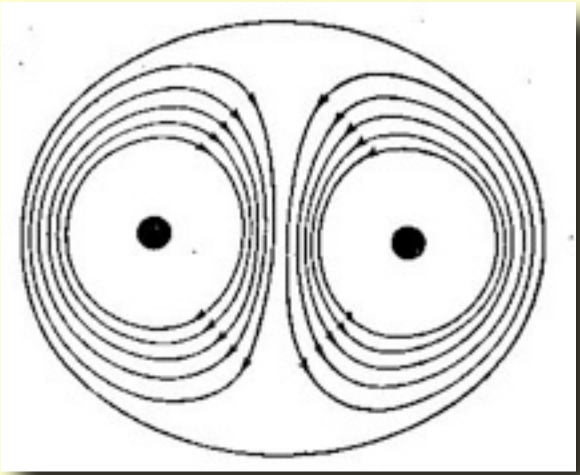
NUMBER OF CORPUSCLES IN ORDER—*continued*.

21	21	21	21	21	21	21	21	22	22	22	22	22	22	22	22	23	23	23	23	23	23	23	24
17	18	18	18	18	18	19	19	19	19	19	20	20	20	20	20	20	20	20	20	20	21	21	21
15	15	15	15	16	16	16	16	16	16	16	16	16	16	17	17	17	17	17	17	17	17	17	17
11	11	11	11	11	12	12	12	12	12	13	13	13	13	13	13	13	13	14	14	15	15	15	15
5	5	6	7	7	7	7	8	8	8	8	8	8	9	9	10	10	10	10	10	10	10	11	11
1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	3	3	4	4	5	5	5	5	5

24	24	24	24	24	24	24
21	21	21	21	21	21	21
17	18	18	18	18	18	19
15	15	15	15	16	16	16
11	11	11	11	11	12	12
5	5	6	7	7	7	7
1	1	1	1	1	1	1

We can investigate the equilibrium of corpuscles in one plane by experiment as well as by analysis, using a method introduced for a different purpose by an American physicist, Professor Mayer. The problem of the arrangement of the corpuscles is to find how a number of bodies which repel each other with forces inversely proportional to the square of the distance between them will arrange themselves when under the action of an attractive force tending to drag them to a fixed point. For the experimental method the corpuscles are replaced by magnetised needles pushed through cork discs and floating on water. Care should be taken that the needles are equally magnetised. These needles, having their poles all pointing in the same way, repel each other like the corpuscles. The attractive force is produced by a large magnet placed above the surface of the water, the lower pole of this magnet being of the opposite sign to that of the upper poles of the floating magnets. The component along the surface of the water of the force due to this magnet is directed to the point on the surface vertically below the pole of the magnet, and is approximately proportional to the distance from this point. The forces acting on the magnets are thus analogous to those acting on the corpuscles.

If we throw needle after needle into the water we shall find that they will arrange themselves in definite patterns, three needles at the corners of a triangle, four at the corners of a square, five at the corners of a pentagon; when, however,



”The corpuscular theory of matter with its assumptions of electrical charges and the forces between them is not nearly so fundamental as the vortex theory of matter...”

J. J. Thomson (1906)

”The most interesting hypothesis is that of Sir William Thomson, who supposes each Atom of matter to be a Vortex-ring in the universal Ether. The ether itself we do not directly perceive; but this hypothesis would render our perception of matter a phenomenon of exactly the same order as that of light or radiant heat, viz., a perception of Matter as a Mode of Motion of the Ether.

If one looks at a smoke-ring blown from a cannon, from a locomotive-engine chimney, from a tobacco-pipe, the lips of a smoker, or from an exploded bubble of phosphuretted hydrogen, it will be seen that the whole of the matter of the ring is in a state of rotation round an axis disposed in a circular form, and having no free ends. This is a Vortex-Ring; and such is that motion in the ether which is supposed to constitute a vortex-atom.”

Alfred Daniell, ***A Text-book of the Principles of physics*** (1884)

”A rotating ring of this kind in an imperfect fluid such as air must be the result of friction; but in a perfect fluid it could only originate by a special creation of some kind. Such a vortex-atom in a perfect fluid would have the following properties: it could move about in the fluid; its volume would be invariable; it would be indestructible; if struck by another it would be indivisible, but would present perfect elasticity, for though for the moment distorted, it would recoil and oscillate through its mean form: it would thus be capable of harmonic vibration, as the spectroscope shows the particles of matter to be; it would be capable of changes of form, becoming narrow and thick, or wide and thin; and it is practically the only form of motion in the ether which could remain in or near the same mean position, and at the same time be capable of being compounded with movements of translation.”

Alfred Daniell, ***A Text-book of the Principles of physics*** (1884)

”The electron thus appears to be the smallest definite unit of mass with which we are acquainted. The view has been put forward that all matter is composed of electrons. On such a view an atom of hydrogen for example is a very complicated structure consisting possibly of a thousand or more electrons. The various elements differ from one another in the number and arrangement of electrons, which compose the atom.”

Ernest Rutherford, *Trans. Royal Soc. Canada*, 1902

1906 Nobel Prize in physics for
Joseph John Thomson

”in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases.”

"At first there were very few who believed in the existence of these bodies smaller than atoms. I was even told long afterwards by a distinguished physicist who had been present at my lecture at the Royal Institution that he thought I had been 'pulling their legs'. I was not surprised at this, as I had myself come to this explanation of my experiments with great reluctance, and it was only after I was convinced that the experiment left no escape from it that I had published my belief in the existence of bodies smaller than atoms."

J. J. Thomson, *Recollections and reflections* (1936)

Zahlentafel 1. Elementarteilchen und Photonen.[1]

Name des Teilchens, Entdecker und Jahr der Entdeckung	Zeichen	Ruhmasse in Gramm	Atomgewicht 1 ME $= \frac{m_O}{16} = 1{,}661 \,.\, 10^{-24}$ g	Elektrische Ladung in e. st. E. ($\mathrm{cm}^{\frac{3}{2}}\ \mathrm{g}^{\frac{1}{2}}\ \mathrm{sec}^{-1}$)	Beobachter
Elektron (β-Teilchen): J. W. Hittorf, 1869; J. Perrin, 1895; P. Lenard, 1899	β, e^-	$m_e = (9{,}118 \pm 0{,}010) \,.\, 10^{-28}$	$A_e = 0{,}000549$	$-e$; $e = (4{,}805 \pm 0{,}005) \,.\, 10^{-10}$	
Positron: P. A. M. Dirac, 1928; C. D. Anderson, 1932	e^+	m_e	A_e	$+e$	
Proton (H^+-Teilchen): Marsden, 1914	${}^1_1p$, ${}^1_1\mathrm{H}$	$m_p = (1{,}673 \pm 0{,}010) \,.\, 10^{-24}$; $m_{\mathrm{H}} = (1{,}674 \pm 0{,}010) \,.\, 10^{-24}$	$A_p = 1{,}00758 \pm 0{,}00002$; $A_{\mathrm{H}} = 1{,}00813 \pm 0{,}00002$	$+e$	Bainbridge und Jordan
Neutron: J. Chadwick, 1932	${}^1_0n$	$m_n = (1{,}676 \pm 0{,}010) \,.\, 10^{-24}$	$A_n = 1{,}00897 \pm 0{,}00006$	0	
Deuteron (Deuton): H. C. Urey, F. G. Brickwedde, G. M. Murphy, 1932	${}^2_1d$, ${}^2_1\mathrm{H}$, ${}^2_1\mathrm{D}$	$m_d = (3{,}345 \pm 0{,}020) \,.\, 10^{-24}$; $m_{\mathrm{D}} = (3{,}346 \pm 0{,}020) \,.\, 10^{-24}$	$A_d = 2{,}01418 \pm 0{,}00002$; $A_{\mathrm{D}} = 2{,}01473 \pm 0{,}00002$	$+e$	Bainbridge und Jordan
α-Teilchen (Heliumkern): H. Becquerel, 1896	${}^4_2\alpha$, ${}^4_2\mathrm{He}$	$m_\alpha = (6{,}647 \pm 0{,}040) \,.\, 10^{-24}$; $m_{\mathrm{He}} = (6{,}649 \pm 0{,}040) \,.\, 10^{-24}$	$A_\alpha = 4{,}00279 \pm 0{,}00007$; $A_{\mathrm{He}} = 4{,}00389 \pm 0{,}00007$	$+2e$	Bainbridge und Aston
Photon (Lichtquant, γ-Quant): M. Planck, 1900; A. Einstein, 1905	γ	Masse $m_\nu = \frac{h\nu}{c^2} = 7{,}36 \,.\, 10^{-48}\,\nu$; $h = (6{,}62 \pm 0{,}01) \,.\, 10^{-27}$ erg . sec; $c = (2{,}99774 \pm 0{,}00001) \,.\, 10^{10}$ cm . sec^{-1}	$A_\nu = \frac{16\, m_\nu}{m_O} = \frac{16\, h\nu}{m_O\, c^2} = 4{,}42 \,.\, 10^{-24}\,\nu$, ν in Hertz (sec^{-1})	0	

[1] Die *Massenzahlen*, e, h und c nach „Tables annuelles des constantes et données numériques". Paris, Hermann & Cie. 1937; die *Atomgewichte* nach M. Stanley Livingston und H. A. Bethe, Reviews of Modern Physics, 9, 380, 1937. Über das *Neutrino* s. S. 79.

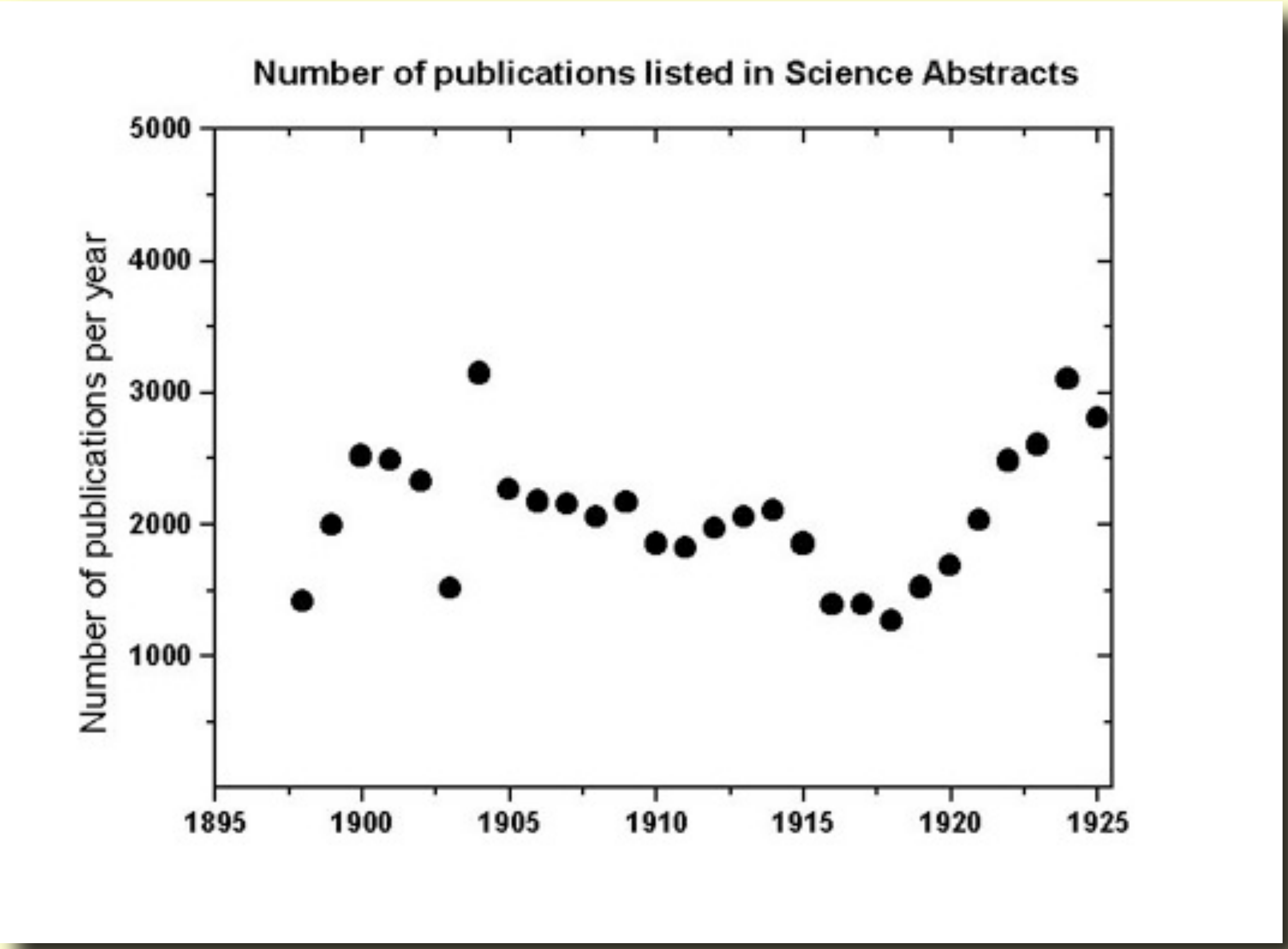
H. A. Bauer, *Grundlagen der Atomphysik*, Wien 1938

The state of physics in 1900

Number of physicists in 1900

Country	Heilbron's estimate	Kudriavcev's estimate	Number taken	"Top" physicists (estimate 1)	"Top" physicists (estimate 2)
Argentina		4	4		
Austro-Hungary	79	53***	79	6	11
Belgium	17		17		1
British Empire*	171	~100	171	35	30
Bulgaria		2	2		1
France	145	~90	145	34	29
Germany	195	~120	195	52	50
Netherlands	31	~15	31	7	8
Italy	73	~50	73	7	4
Japan	11	8	11		2
Portugal		8	8		
Romania		5	5		
Russia	40	50	50	9	25
Serbia		3	3		
Spain		13	13		
Sweden/Norway**	34****		34	5	8
Switzerland	47		47	2	3
United States	195	~110	195	27	22
			1083	(184)	(194)
* with India and Canada					
** Union until 1905					
*** 33 Austrians, 8 Hungarians, 6 Poles, 4 Czechs					
**** With Denmark and Finland					

"Top" physicists
Estimate 1: Dictionary of Scientific Biography (ed. C. C. Gillespie, 1970)
Estimate 2: Fiziki - biograficzeskij sprawocznik (Yu. A. Khramov, 1983)


Number of publications listed in Science Abstracts
Number of publications per year
5000
4000
3000
2000
1000
1895
1900
1905
1910
1915
1920
1925

Science Abstracts 1900

SUBJECT INDEX.

To facilitate reference to any desired subject, the Index is divided into the following sections arranged alphabetically. If any of these are absent this may be taken as an indication that no Abstracts dealing with those particular subjects have been included in this volume.

The numbers refer to Abstracts, those in italics referring to References.

In General Physics:—Apparatus and Instruments (physical, excluding electrical, descriptive); Astronomy; Elasticity; Gravity; Measurements; Meteorology, &c.; Miscellaneous; Surface Tension; Theories.

In Light:—Absorption (light and heat); Dispersion; Interference; Measurements; Miscellaneous; Phosphorescence and Fluorescence; Photography; Photometry; Polarisation; Rays; Reflection; Refraction; Spectra; Vision; Zeeman Effect and Radiation in a Magnetic Field.

In Heat:—Absorption (light and heat); Conductivity (thermal); Critical Points and Constants; Dilatation; Freezing-, Melting-, and Boiling-Points; Gases and Vapours; Measurements; Miscellaneous; Specific Heat and Latent Heat; Temperature; Temperatures (high and low); Thermodynamics; Vapour Pressure.

In Sound:—All Abstracts referring to this subject have been indexed under *Sound*.

In Electricity and Magnetism:—Absorption; Alternate Current Research; Apparatus and Instruments (descriptive); Capacity (electrostatic); Conductivity and Resistivity; Dielectrics; Discharge in Gases and in Vacuo; Induction; Induction (self and mutual); Measurements; Medical Electricity; Miscellaneous; Oscillations and Waves; Polarisation (electric waves); Polarisation (electrolytic); Resonance; Static Electricity; Terrestrial Magnetism and Electricity; Thermo-Electricity and Thermo-Magnetism.

In Chemical Physics:—Absorption; Batteries (primary); Batteries (secondary); Chemical Equilibrium; Dissociation and Ionisation; Electric Furnace Processes; Electrolysis (commercial); Electrolysis (except commercial); Electrolytic Analysis; Miscellaneous; Osmosis; Solution and Solubility; Vats and Cells (electrolytic).

In Steam Plant, Gas and Oil Engines:—Accessories (steam plant); Automobiles; Boilers; Condensers; Economisers and Feed Water Heaters; Gas Engines, Gas Producers, &c.; Miscellaneous; Oil Engines; Steam Engines.

In General Electrical Engineering:—Accessories and Appliances (electrical, excluding traction); Apparatus and Instruments (descriptive); Batteries (primary); Batteries (secondary); Equipment of Factories and Machine Tools; Insulation and Insulators; Miscellaneous.

In Generators, Motors, and Transformers:—Alternators; Dynamos; Miscellaneous; Motors; Rectifiers; Transformers and Rotary Converters.

In Power Transmission, Traction, and Lighting:—Accessories and Appliances (traction); Automobiles; Cables, Conductors and Wiring; Costs; Electricity Works (descriptive); Lamps (arc) and Arc Lighting; Lamps (incandescent); Miscellaneous; Power Transmission and Distribution; Traction (electric, by accumulators); Traction (excluding accumulator traction and descriptions of power stations); Traction (mechanical).

In Telegraphy and Telephony:—Telegraphy (excluding wireless telegraphy); Telegraphy (wireless); Telephony.

Supplementary Index of Works and Installations described in this Volume, p. 1099.

one third of papers listed in Science Abstracts 1900 technology

Science Abstracts 1900

SUBJECT INDEX.

To facilitate reference to any desired subject, the Index is divided into the following sections arranged alphabetically. If any of these are absent this may be taken as an indication that no Abstracts dealing with those particular subjects have been included in this volume.

The numbers refer to Abstracts, those in italics referring to References.

17.1% *In General Physics*:—Apparatus and Instruments (physical, excluding electrical, descriptive); Astronomy; Elasticity; Gravity; Measurements; Meteorology, &c.; Miscellaneous; Surface Tension; Theories.

17.0% *In Light*:—Absorption (light and heat); Dispersion; Interference; Measurements; Miscellaneous; Phosphorescence and Fluorescence; Photography; Photometry; Polarisation; Rays; Reflection; Refraction; Spectra; Vision; Zeeman Effect and Radiation in a Magnetic Field.

10.7% *In Heat*:—Absorption (light and heat); Conductivity (thermal); Critical Points and Constants; Dilatation; Freezing-, Melting-, and Boiling-Points; Gases and Vapours; Measurements; Miscellaneous; Specific Heat and Latent Heat; Temperature; Temperatures (high and low); Thermodynamics; Vapour Pressure.

1.6% *In Sound*:—All Abstracts referring to this subject have been indexed under *Sound*.

31.0% *In Electricity and Magnetism*:—Absorption; Alternate Current Research; Apparatus and Instruments (descriptive); Capacity (electrostatic); Conductivity and Resistivity; Dielectrics; Discharge in Gases and in Vacuo; Induction; Induction (self and mutual); Measurements; Medical Electricity; Miscellaneous; Oscillations and Waves; Polarisation (electric waves); Polarisation (electrolytic); Resonance; Static Electricity; Terrestrial Magnetism and Electricity; Thermo-Electricity and Thermo-Magnetism.

22.6% *In Chemical Physics*:—Absorption; Batteries (primary); Batteries (secondary); Chemical Equilibrium; Dissociation and Ionisation; Electric Furnace Processes; Electrolysis (commercial); Electrolysis (except commercial); Electrolytic Analysis; Miscellaneous; Osmosis; Solution and Solubility; Vats and Cells (electrolytic).

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In Telegraphy and Telephony:—Telegraphy (excluding wireless telegraphy); Telegraphy (wireless); Telephony.

Supplementary Index of Works and Installations described in this Volume, p. 1099.

one third of papers listed in Science Abstracts 1900 technology

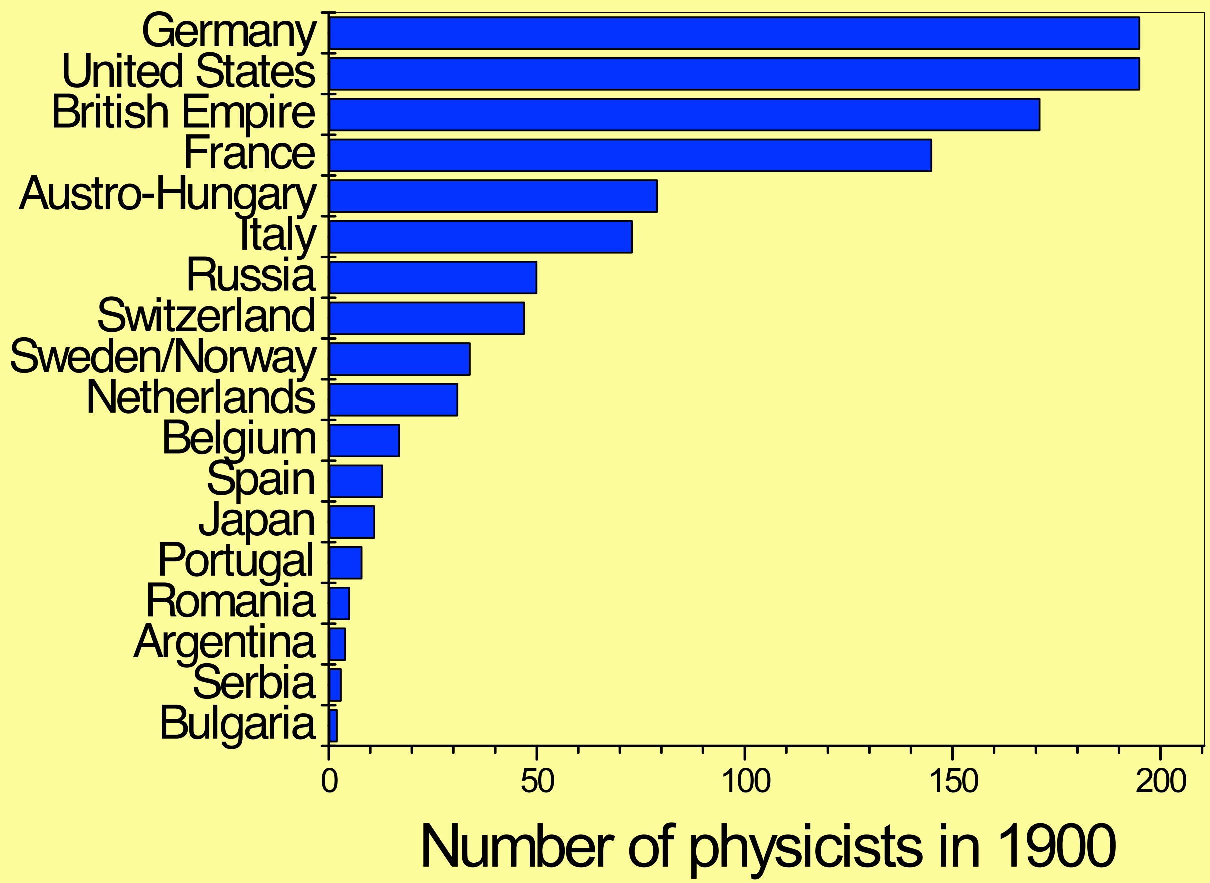
Number of active physicists in 1900

1. Direct ”head counting” > 1083

2. *Adressbuch der lebender Physiker, Mathematiker und Astronomer* < 1290

3. Science Abstracts for 1900 0.7 x 1658 = 1200

the three idenpendent estimates give similar result


Germany
United States
British Empire
France
Austro-Hungary
Italy
Russia
Switzerland
Sweden/Norway
Netherlands
Belgium
Spain
Japan
Portugal
Romania
Argentina
Serbia
Bulgaria
0
50
100
150
200
Number of physicists in 1900

Best known physicists of 1900

Germany: Max Abraham, Paul Drude, Friedrich Kohlrausch, Philip Lenard, Otto Lummer, Walther Nernst, Max Planck, Ernst Prinsgheim, Wilhelm Conrad Röntgen, Heinrich Rubens, Emil Warburg, Wilhelm Wien

Great Britain: William Crookes, James Dewar, Joseph Larmor, Oliver Lodge, John Poynting, George Stokes, William Strutt (Lord Rayleigh), John Joseph Thomson, William Thomson (Lord Kelvin)

France: Emil Amagat, Henri Becquerel, Marcel Brillouin, Alfred Cornu, Pierre Curie, Marie Skłodowska-Curie, Gabriel Lippmann, Eleuthere Mascart, Jean Perrin, Henri Poincaré

United States: Josiah Gibbs, Samuel Langley, Albert Michelson, Henry Rowland, Robert Wood

Netherlands: Heike Kamerlingh-Onnes, Hendrik Lorentz, Johannes Van der Waals, Pieter Zeeman

Austro-Hungary: Ludwig Boltzmann, Roland Eötvös

Russia: Piotr Lebedev

Sweden: Johannes Rydberg

Short tradition of international congresses

First International Congress of Chemists Karlsruhe, 1860	140
First International Congress of Mathematicians Zurich, 1894	<100
First International Congress of Physicists Paris, 1900	~800

"The committee deliberately rejected the method of simply presenting personal memoirs, or notes on limited subjects, and concentrated all its efforts upon the preparation of a well-arranged summary of the actual state of physical science, in the branches in which, within the last few years, the greatest progress has been made, and the actual stage of progress of which at the end of the nineteenth century it was considered most important to investigate. Once the list of subjects was completed, the work was divided among the physicists who seemed best qualified to give a complete representation of their special subjects. This plan gave rise to a series of reports, many of which are works of a very high value, and which, in their entirety, constitute the most complete representation of any science at a given epoch yet made."

Ch. E. Guillaume,
Secretary of the Organizing Committee

RAPPORTS

PRÉSENTÉS AU

CONGRÈS INTERNATIONAL

DE

PHYSIQUE

RÉUNI A PARIS EN 1900

SOUS LES AUSPICES DE LA SOCIÉTÉ FRANÇAISE DE PHYSIQUE,

RASSEMBLÉS ET PUBLIÉS PAR

CH.-ÉD. GUILLAUME ET L. POINCARÉ,

Secrétaires généraux du Congrès.

TOME I.

QUESTIONS GÉNÉRALES. — MÉTROLOGIE.
PHYSIQUE MÉCANIQUE. — PHYSIQUE MOLÉCULAIRE.

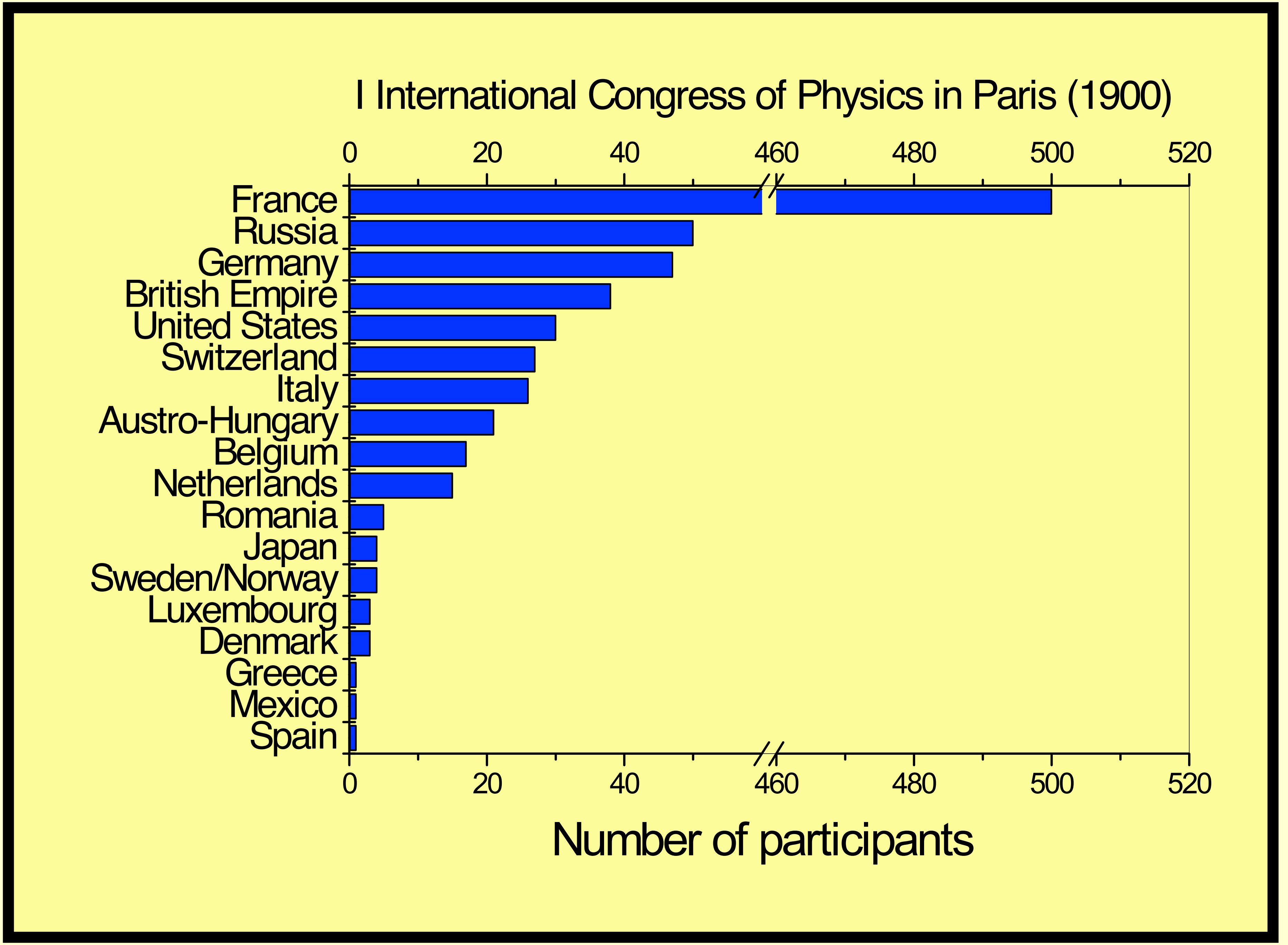
PARIS,

GAUTHIER-VILLARS, IMPRIMEUR-LIBRAIRE

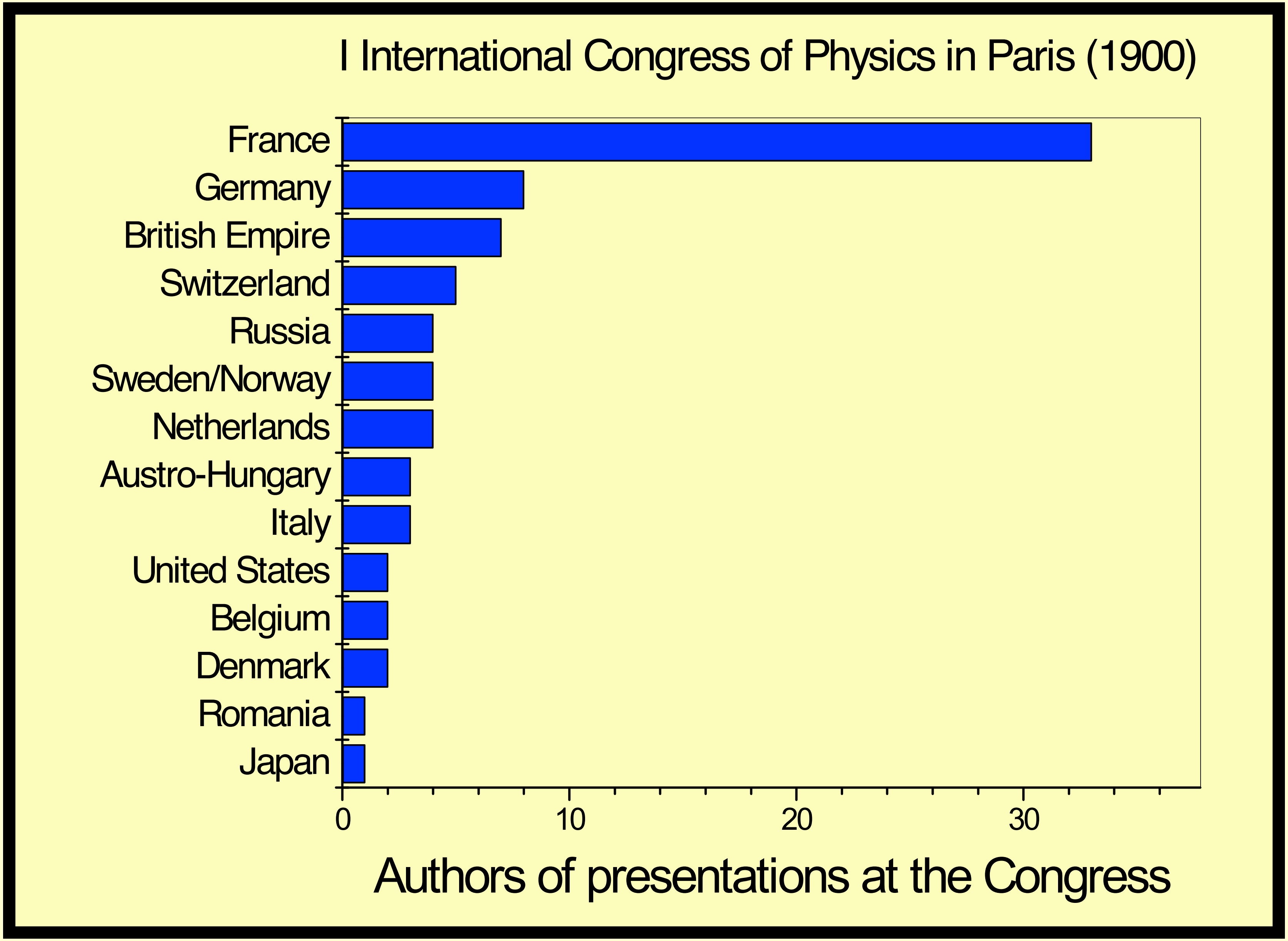
DU BUREAU DES LONGITUDES, DE L'ÉCOLE POLYTECHNIQUE,

Quai des Grands-Augustins, 55.

1900



I International Congress of Physics in Paris (1900)
0
20
40
460
480
500
520
France
Russia
Germany
British Empire
United States
Switzerland
Italy
Austro-Hungary
Belgium
Netherlands
Romania
Japan
Sweden/Norway
Luxembourg
Denmark
Greece
Mexico
Spain
Number of participants



I International Congress of Physics in Paris (1900)
France
Germany
British Empire
Switzerland
Russia
Sweden/Norway
Netherlands
Austro-Hungary
Italy
United States
Belgium
Denmark
Romania
Japan
0
10
20
30
Authors of presentations at the Congress

I International Congress of Physics
Paris, 6 -12 August, 1900

Sections of Congress :

1. General problems and metrology
2. Mechanics and molecular physics
3. Optics and thermodynamics
4. Electricity and magnetism
5. Magnetooptics, cathode rays, uranium rays etc.
6. Cosmic physics
7. Biological physics

Problems discussed in Section 1:

Mathematical physics and experimental physics (H. Poincaré)
Accuracy of measurements in metrology (Benoit)
National laboratories (Pellat)
Review of proposed systems of units (Guillaume)
Interferometric measurements in metrology (Macé de Lépinay)
Velocity of sound (Violle)
Thermometric scales (Chappuis)
Advances in pirometry (Barus)
Mechanical equivalent of heat (Ames)
Specific heat of water (Griffiths)
Standard of electromotive force (Gouy)
Electrochemical equivalent of silver, copper and water (Leduc)
Studies of level surface on earth and changes of gravity in a magnetic field (Eötvös)
Distribution of gravity on earth's surface (Bourgeois)
Gravitation constant (Boys)

Problems discussed in Section 2:

Symmetry and elasticity of crystals (Voigt)
Deformations of solids (Mensager)
Solids under pressure (Spring)
Constitution of alloys (Roberts-Austen)
Formation of crystals at constant temperature (Van’t Hoff)
Calorimetry of liquids (Battelli)
Statics of liquids (Amagat)
Statics of mixed fluids (Van der Waals)
Rigidity of liquids (Schwedoff)
Determination of critical constants (Mathias)
Critical refractive index (Galitzin)
Osmosis (Perrin)
Diffusion of gases (Brillouin)
Capillarity (Van de Mensbrugghe)
Melting and cristallisation (Weinberg)
Migratory deformations in solids (Guillaume)
Hydrodynamical actions at a distance (Bjerknes)
Specific heat of gases (Battelli)

Problems discussed in Section 3:

Ether waves (W. Thomson)
Distribution of spectral lines (Rydberg)
Dispersion (Carvallo)
Radiation of black bodies (Lummer)
Radiation of gases (Pringsheim)
Theoretical laws of radiation (Wien)
Optical properties of metals (Drude)
Velocity of light (Cornu)
Radiation pressure (Lebedev)
Kinetic theory of gases and Carnot principle (Lippmann)
Advances in the theory of heat engines (Witz)

Problems discussed in Section 4:

Propagation of electrical energy in electromagnetic field (Poynting)
The ratio of electromagnetic and electrostatic units (Abraham)
Velocity of electric waves (Blondlot and Gutton)
Hertz waves (Righi)
Radioinductors (Coherers) (Branly)
Gaseous dielectrics (Bouty)
Electrolysis and ionisation (Arrhenius)
Hysteresis (Warburg)
Contact electricity (Christiansen)
Magnetic properties of matter (Du Bois)
Magnetostriction (Nagaoka)
Modifications caused by magnetisation (Hurmuzescu)
Transformations of carburised iron (Van't Hoff)
Registration of variable currents (Blondel)
Theory of electric cells (L. Poincaré)
Electric arc (Lang)
Polyphase currents (Potier)

Problems discussed in Section 5:

Theory of magnetooptical phenomena (Lorentz)
Theory of dispersion in metals (Drude)
Actinoelectric phenomena (Bichat and Swyngedauw)
Ionised gases (Villari)
Information on the structure of matter from studies of electric discharges in gases (J. J. Thomson)
Cathode rays (Villard)
Uranium rays (Becquerel)
New radioactive elements and their radiation (M. & P. Curie)

Problems discussed in Section 6:

Physical structure of the sun (Birkeland)
Solar constant (Crova)
Comparison of light of the sun and the stars (Dufour)
Atmospheric electricity (Exner)
Study of northern lights (Paulsen)
Ice and glaciers (Hagenbach)
Oscillations of lakes (Forel and Sarasin)

Problems discussed in Section 7:

Transmission of energy in organisms (Broca)
Retina phenomena (Charpentier)
Accomodation (Tscherning)
Molecular phenomena caused by electricity in inorganic and living matter (Bose)
Applications of spectroscopy in biology (Hénocque)

The origin and reception of quantum theory

Black body radiation

1860 Gustav Kirchhoff – idea of the (perfect) black body with universal distribution of emissive power $e(\lambda,T)$

1879 Josef Stefan - $\int e(\lambda,T)d\lambda \sim T^4$ from experiments

1884 Ludwig Boltzmann - theoretical derivation of Stefan's law

1886 Samuel Langley – measurement of the spectral distribution of sun's radiation

1887 Vladimir Aleksandrovich Michelson – first formula for $e(\lambda,T)$

$$e(\lambda,T) = a\, T^{3/2}\lambda^{-6} \exp(-b/\lambda^2 T)$$

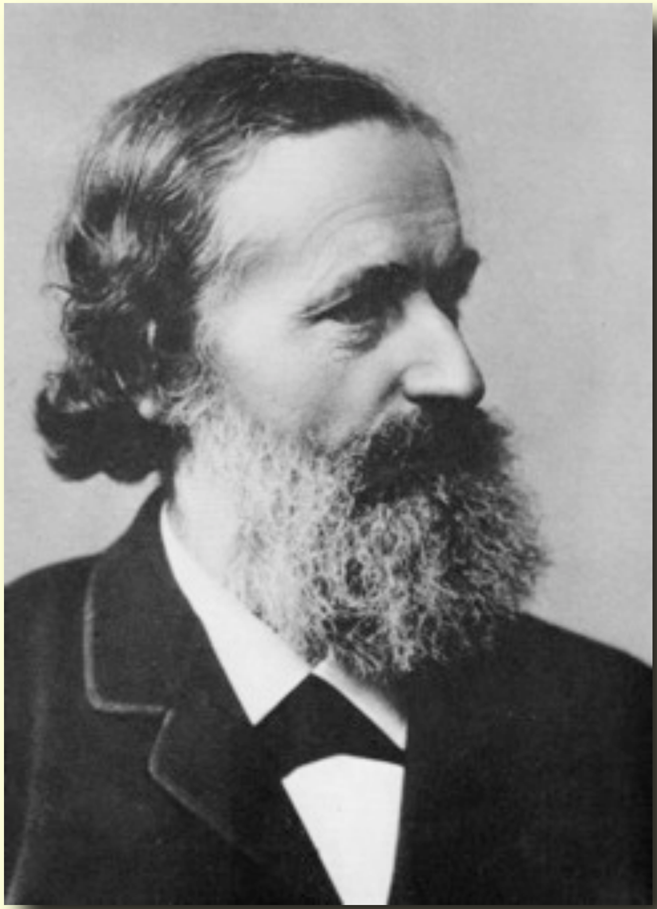
1888 Heinrich Weber - $e(\lambda,T) = a\, \lambda^{-2} \exp(cT - b/\lambda^2 T^2)$

1893 Wilhelm Wien - $\lambda_{max} T = constans$

1896 Wilhelm Wien - $e(\lambda,T) = a\, \lambda^{-5} \exp(-b/\lambda T)$

1896 Friedrich Paschen - $e(\lambda,T) = a\, \lambda^{-5,6} \exp(-b/\lambda T)$

Black body radiation



Gustav Kirchhoff
(1859)

$$\frac{e(\lambda,T)}{a(\lambda,T)} = f(\lambda,T)$$

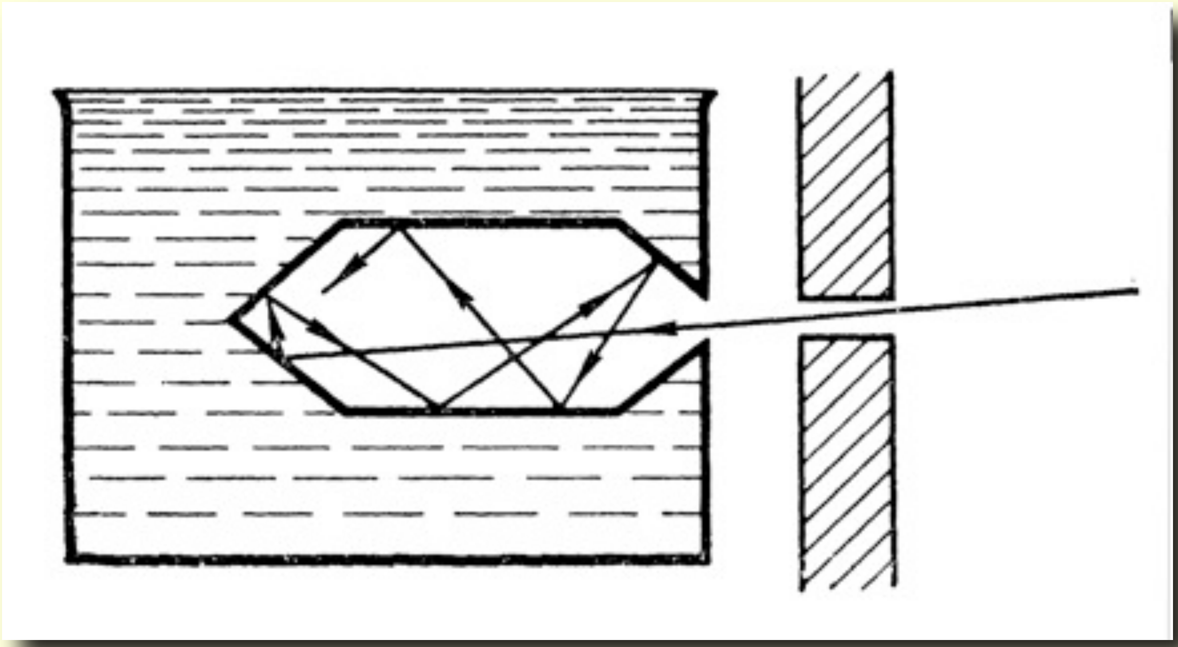
Emissive power of every body is proportional to its absorptive power

Perfect black body

$$a_c\left(\lambda, T\right) \equiv 1$$

$$\frac{e_c\left(\lambda, T\right)}{a_c\left(\lambda, T\right)} = e_c\left(\lambda, T\right) = f\left(\lambda, T\right)$$

A model of black body



One can thus measure emission of black body and try to find a formula describing it

Black body radiation

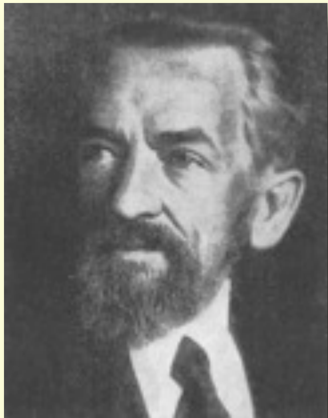
A proposal by Wilhelm Wien (1896)

$$e_c(\lambda, T) = a\lambda^{-5}\exp(-b/\lambda T)$$

Black body radiation

A proposal by John William Strutt (Lord Rayleigh) (1900)

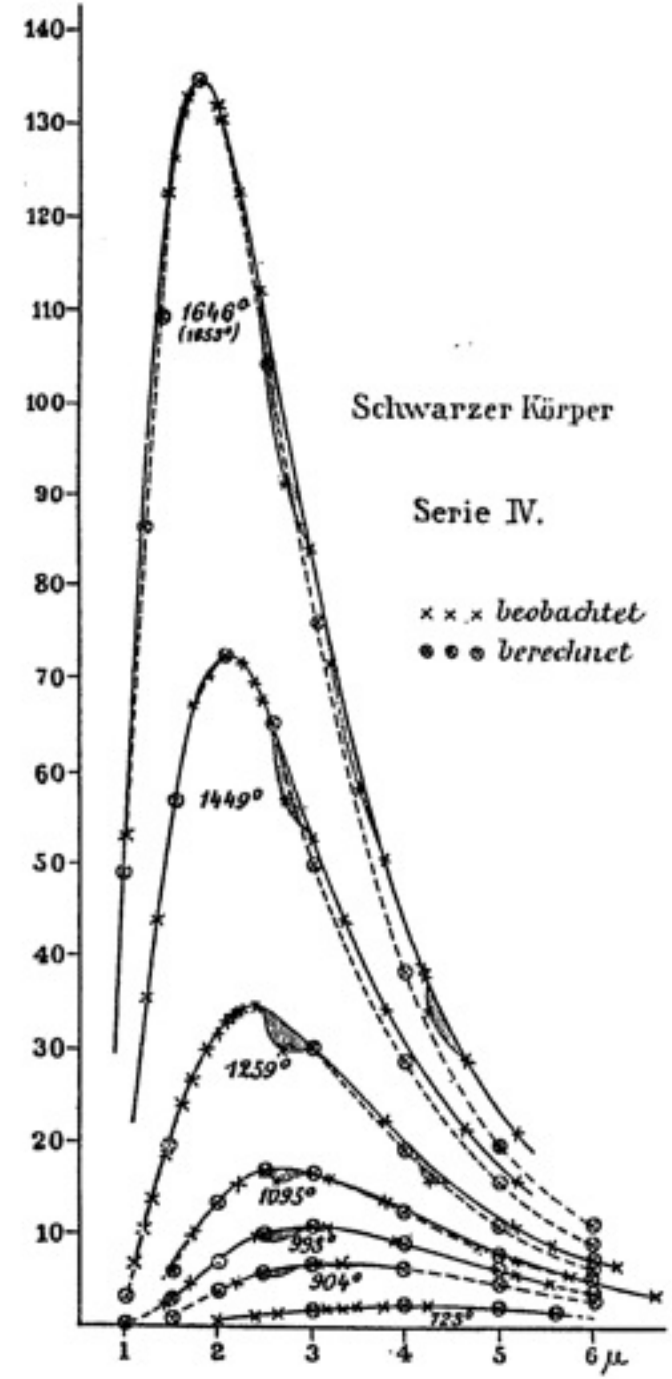
$$e_c(\lambda, T) = aT\lambda^{-4}\exp(-b/\lambda T)$$



Otto Lummer

Ernst Pringsheim

The first precise measurements of the black-body radiation for large wavelengths (1899)



Sunday, October 7, 1900

Planck and his wife invited friends for an afternoon tea party. During this gathering Rubens told Planck that the newest results of measurements which he performed with Kurlbaum showed deviations from the Wien's radiation formula. After the guests have left, Planck sat at his desk and still the same evening found an improvement of Wien's formula.

He presented his phenomenological formula for black body radiation intensity on October 19, 1900, at a meeting of the German Physical Society in Berlin.

Planck's lecture
19 X 1900

Max Planck
(1858-1947)

IV.

Verhandlungen der physikal. Gesellschaft 2, p. 202; 1900.

Ueber eine Verbesserung der Wienschen Spektralgleichung. (1)

(Vorgetragen in der Sitzung vom 19. Oktober 1900.)

Die von Herrn Kurlbaum in der heutigen Sitzung mitgeteilten interessanten Resultate der von ihm in Gemeinschaft mit Herrn Rubens auf dem Gebiete der längsten Spektralwellen ausgeführten Energiemessungen haben die zuerst von den Herren Lummer und Pringsheim auf Grund ihrer Beobachtungen aufgestellte Behauptung nachdrücklich bestätigt, daß das Wiensche Energieverteilungsgesetz nicht die allgemeine Bedeutung besitzt, welche ihm bisher von mancher Seite zugeschrieben worden war, sondern daß dies Gesetz vielmehr höchstens den Charakter eines Grenzgesetzes hat, dessen überaus einfache Form nur einer Beschränkung auf kurze Wellenlängen bzw. tiefe Temperaturen ihren Ursprung verdankt [1]). Da ich selber die Ansicht von der Notwendigkeit des Wienschen Gesetzes auch an dieser Stelle vertreten habe, so sei es mir gestattet, hier kurz darzulegen, wie sich die von mir entwickelte elektromagnetische Theorie der Strahlung zu den Beobachtungstatsachen stellt.

Nach dieser Theorie ist das Energieverteilungsgesetz bestimmt, sobald die Entropie S eines auf Bestrahlung ansprechenden linearen Resonators als Funktion seiner Schwingungsenergie U bekannt ist. Ich habe indes schon in meiner letzten Arbeit über diesen Gegenstand hervorgehoben [2]), daß der Satz der Entropievermehrung an und für sich noch nicht hinreicht, um diese Funktion vollständig anzugeben; zur Ansicht von der Allgemeinheit des Wienschen Gesetzes wurde ich vielmehr durch eine besondere Betrachtung geführt, nämlich durch die Berechnung einer unendlich kleinen Entropievermehrung eines in einem stationären Strahlungs-

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[1]) Auch Hr. Paschen hat, wie er mir brieflich mitteilte, neuerdings merkliche Abweichungen vom Wienschen Gesetz festgestellt.

[2]) M. Planck, Ann. d. Phys. 1. p. 730. 1900.

A modest conclusion of Planck's article:

"…one is led to a formula for radiation intensity,

$$e(\lambda, T) = [C\lambda^{-5}]/[\exp(c/\lambda T) - 1],$$

which includes two constants. I can see that this formula describes available results of measurements as precisely as the best of published spectral formulas, that is, those of Thiesen*, of Lummer and Jahnke**, and of Lummer and Pringsheim***... For that reason I dare to draw your attention to this new formula, which – as far as the electromagnetic theory of radiation is concerned – I regard as being the simplest after Wien's formula."

* Thiesen M., Verhandlungen Deutsch. Phys. Ges., **2**, 67 (1900),

** Lummer O., Jahnke E., Ann. Phys. **3**, 288 (1900),

*** Lummer O., Pringsheim E., Verhandlungen Deutsch. Phys. Ges., **2**, 174, 900).

Parameterizations of $e(\lambda,T)$ for black bodies

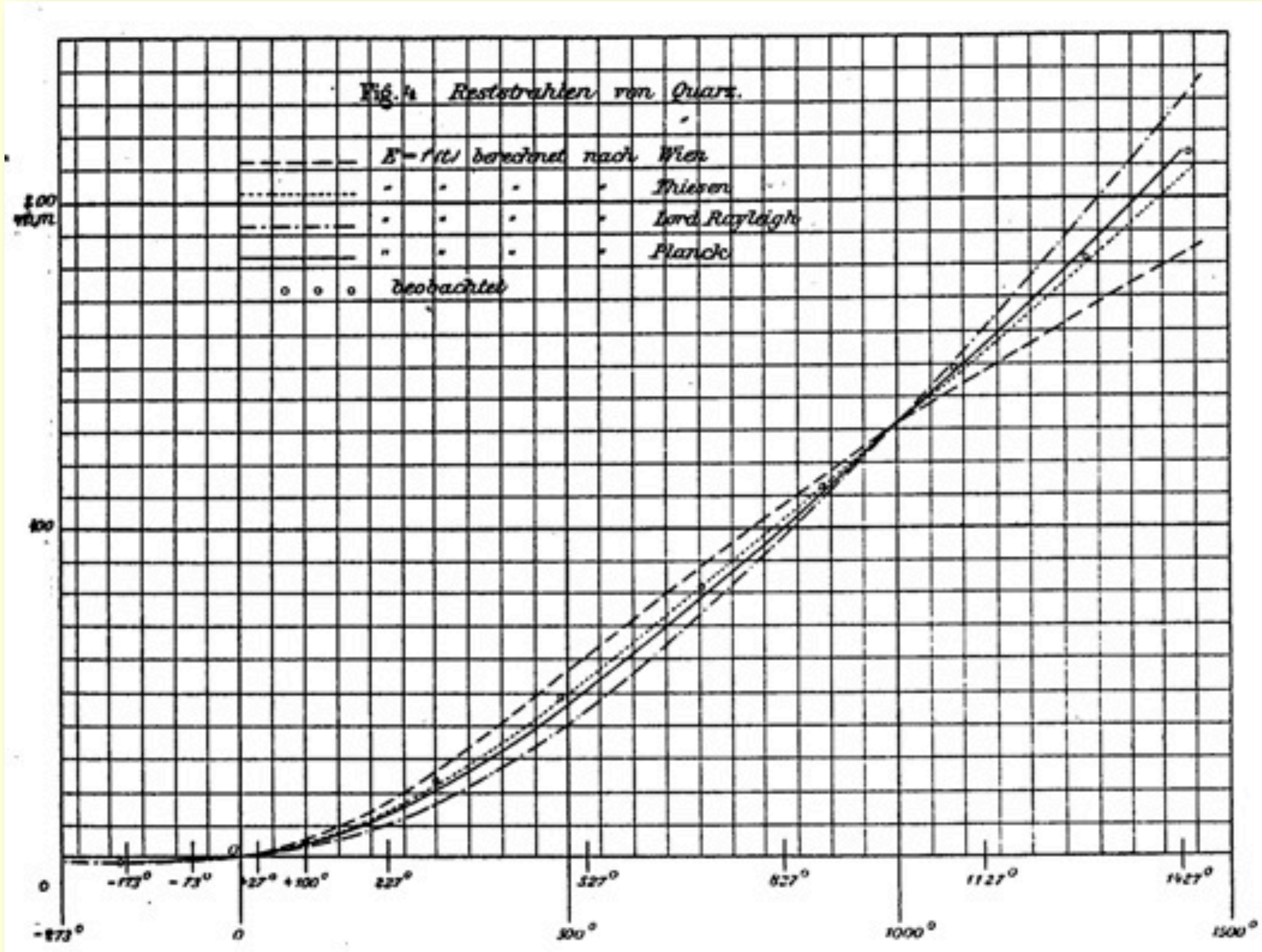
Wien 1896	$a\lambda^{-5}\exp(-b/\lambda T)$
Rayleigh 1900	$aT\lambda^{-4}\exp(-b/\lambda T)$
Lummer, Pringsheim 1900	$aT\lambda^{-4}\exp(-b/(\lambda T)^{1.25})$
Lummer, Jahnke 1900	$a\lambda^{-5}\exp(-b/(\lambda T)^{0.9})$
Thiesen 1900	$aT^{0.5}\lambda^{-4.5}\exp(-b/\lambda T)$
Planck 19 X 1900	$a\lambda^{-5}\left(\dfrac{1}{\exp(b/k\lambda T)-1}\right)$
Planck 14 XII 1900	$8\pi\,\mathrm{hc}\lambda^{-5}\left(\dfrac{1}{\exp(hc/k\lambda T)-1}\right)$

“The very next morning, I received a visit from my colleague Rubens. He came to tell me that after the conclusion of the meeting he had that very night checked my formula against the results of his measurements, and found a satisfactory concordance at every point. Also Lummer and Pringsheim, who first thought to have discovered divergences soon withdrew their objections; for, as Pringsheim related it to me, the observed divergences turned out to have been due to an error in calculation. Later measurements, too, confirmed my radiation formula again and again – the finer the methods of measurements were used, the more accurate the formula was found to be… For this reason, on the very day when I formulated this law, I began to devote myself to the task of investing it with a true physical meaning.”

Max Planck

Heinrich
Rubens

Ferdinand
Kurlbaum



Planck's conclusion:

Emission and absorption of light is not a continuous process but occurs in portions equal $h\nu$

14 XII 1900

The birth of quantum physics

Max Planck

9. *Ueber das Gesetz der Energieverteilung im Normalspectrum;*
von Max Planck.

(In anderer Form mitgeteilt in der Deutschen Physikalischen Gesellschaft, Sitzung vom 19. October und vom 14. December 1900, Verhandlungen 2. p. 202 und p. 237. 1900.)

Einleitung.

Die neueren Spectralmessungen von O. Lummer und E. Pringsheim[1]) und noch auffälliger diejenigen von H. Rubens und F. Kurlbaum[2]), welche zugleich ein früher von H. Beckmann[3]) erhaltenes Resultat bestätigten, haben gezeigt, dass das zuerst von W. Wien aus molecularkinetischen Betrachtungen und später von mir aus der Theorie der elektromagnetischen Strahlung abgeleitete Gesetz der Energieverteilung im Normalspectrum keine allgemeine Gültigkeit besitzt.

Die Theorie bedarf also in jedem Falle einer Verbesserung, und ich will im Folgenden den Versuch machen, eine solche auf der Grundlage der von mir entwickelten Theorie der elektromagnetischen Strahlung durchzuführen. Dazu wird es vor allem nötig sein, in der Reihe der Schlussfolgerungen, welche zum Wien'schen Energieverteilungsgesetz führten, dasjenige Glied ausfindig zu machen, welches einer Abänderung fähig ist; sodann aber wird es sich darum handeln, dieses Glied aus der Reihe zu entfernen und einen geeigneten Ersatz dafür zu schaffen.

Dass die physikalischen Grundlagen der elektromagnetischen Strahlungstheorie, einschliesslich der Hypothese der „natürlichen Strahlung", auch einer geschärften Kritik gegenüber Stand halten, habe ich in meinem letzten Aufsatz[4]) über diesen

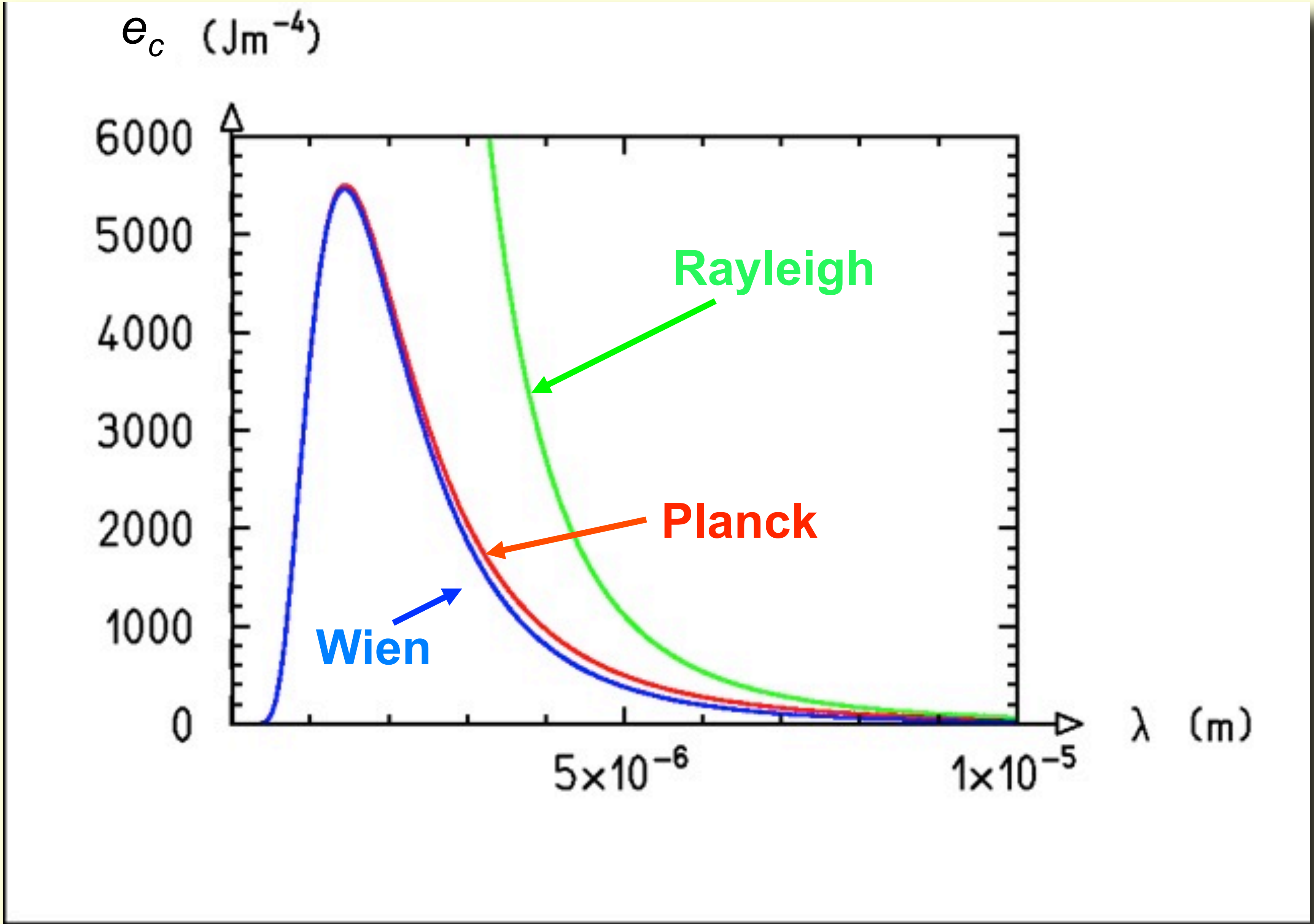
1) O. Lummer u. E. Pringsheim, Verhandl. der Deutsch. Physikal. Gesellsch. 2. p. 163. 1900.

2) H. Rubens und F. Kurlbaum, Sitzungsber. d. k. Akad. d. Wissensch. zu Berlin vom 25. October 1900, p. 929.

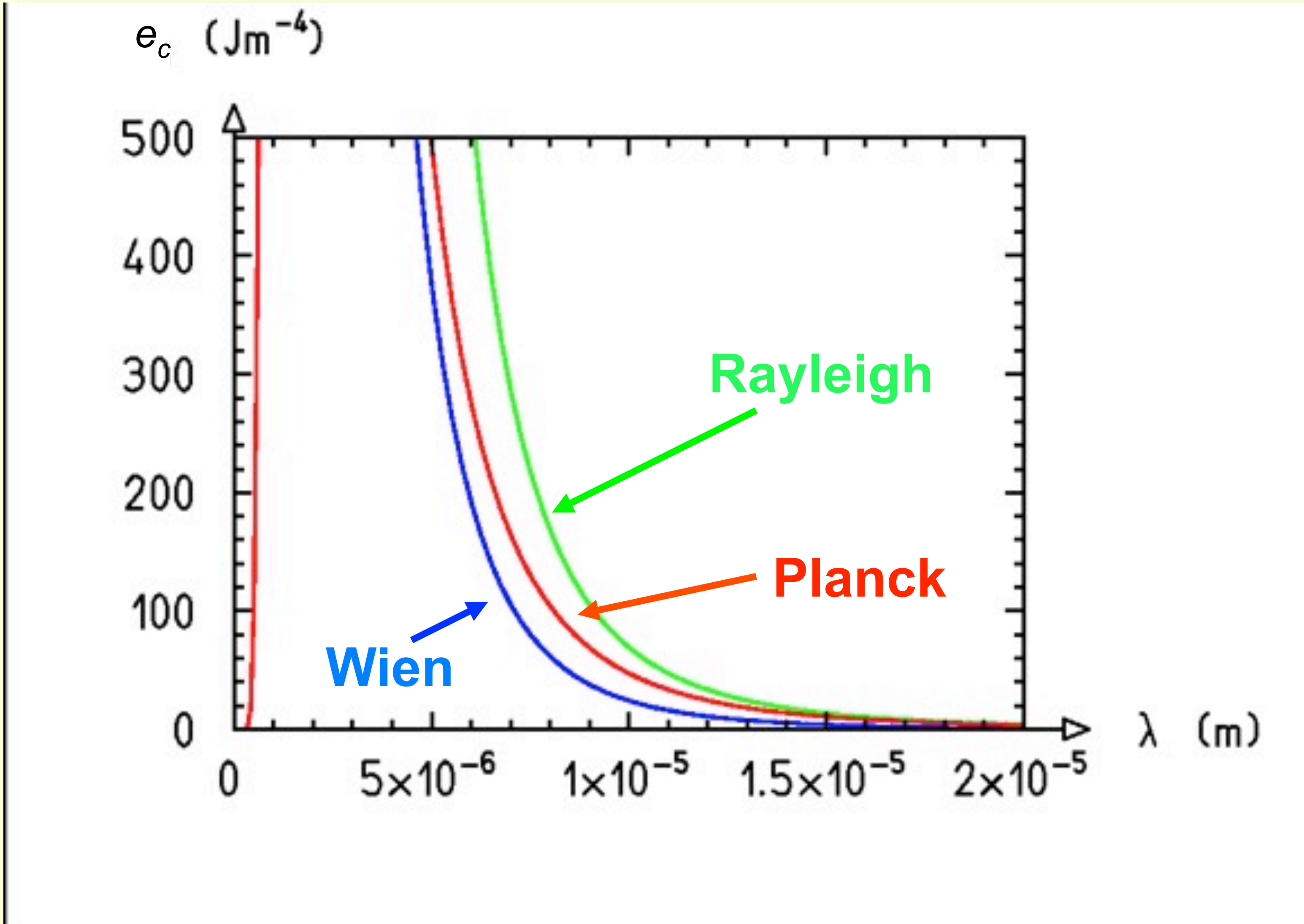
3) H. Beckmann, Inaug.-Dissertation, Tübingen 1898. Vgl. auch H. Rubens, Wied. Ann. 69. p. 582. 1899.

4) M. Planck, Ann. d. Phys. 1. p. 719. 1900.

[*Ann. d. Physik* **4** (1901) 564-566]

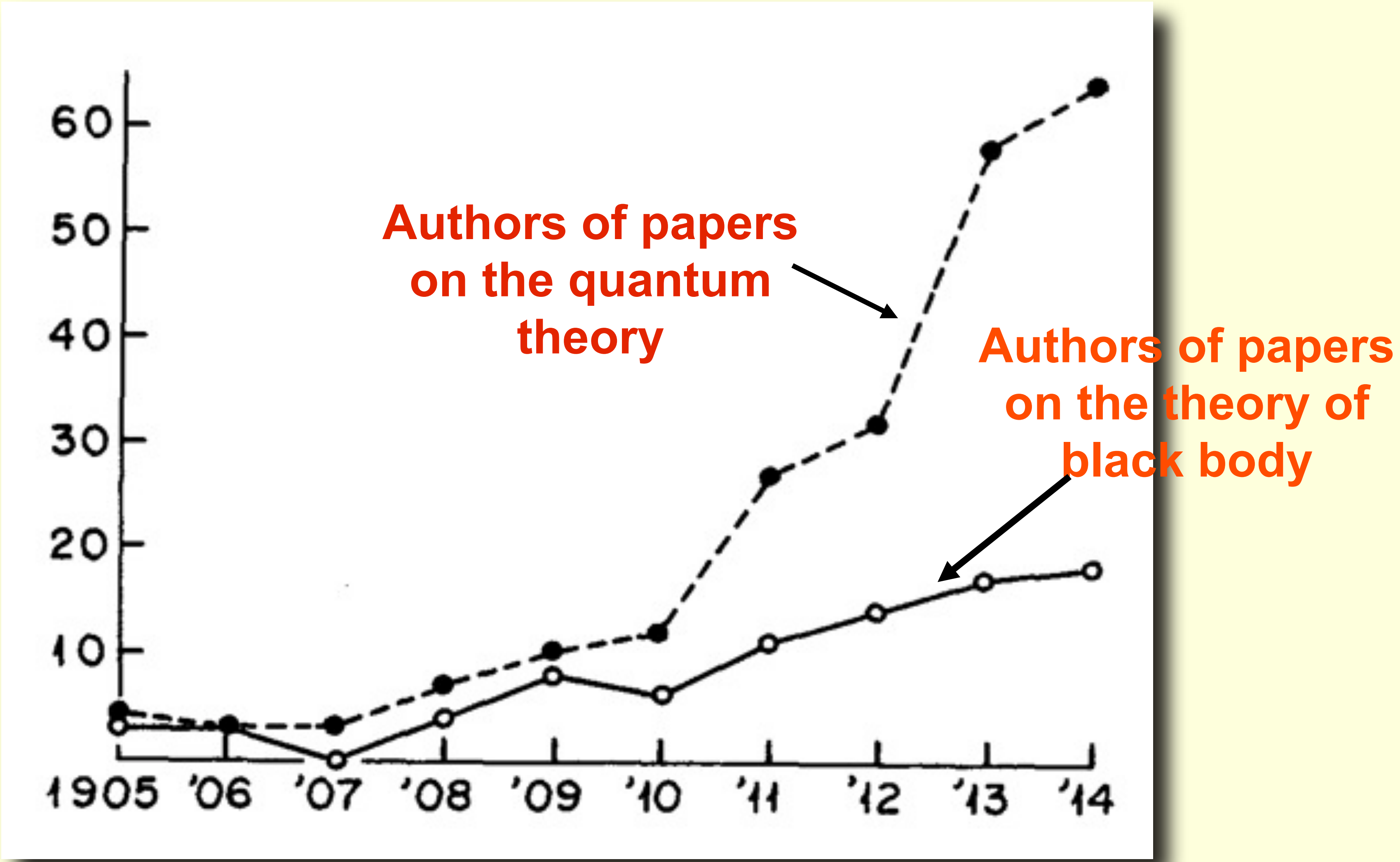


e_c (Jm^{-4})
6000
5000
4000
3000
2000
1000
0
Rayleigh
Planck
Wien
5×10^{-6}
1×10^{-5}
λ (m)



$$e_c(\lambda, T) = 8\pi hc\lambda^{-5}[\exp\{\frac{hc}{k\lambda T} - 1\}]^{-1}$$

Authors of papers on the quantum theory



On the need of time perspective in history

GESCHICHTSTAFELN

DER

PHYSIK

VON

FELIX AUERBACH

LEIPZIG
VERLAG VON JOHANN AMBROSIUS BARTH
1910

Ю.А.ХРАМОВ

БИОГРАФИЯ ФИЗИКИ

ХРОНОЛОГИЧЕСКИЙ СПРАВОЧНИК

Ответственный редактор
акад. АН УССР
А. Г. СИТЕНКО

КИЕВ
«ТЕХНIКА»
1983

The number of important discoveries listed for 1899 and 1900

Geschichtstafeln der Physik
Felix Auerbach
Leipzig 1910

1899	1900
44	69

Биографиа физики
Ю.А.Храмов
Kiev 1983

1899	1900
17	16

The number of important discoveries listed for 1899 and 1900

Geschichtstafeln der Physik
Felix Auerbach
Leipzig 1910

1899	1900
44	69

Биографиа физики
Ю.А.Храмов
Kiev 1983

1899	1900
17	16

The number of important discoveries included in **both** lists

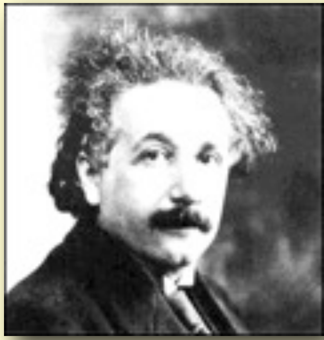
1899	1900
7	7

The seven items, recognized as important by both Auerbach and Khramov:

1. Planck's formula for blackbody radiation (his theory was ***not*** mentioned by Auerbach !),
2) verification of this formula by Rubens and Kurlbaum,
3) discovery of gamma rays by Villard,
4) discovery of the deflection of beta rays by electric field (Dorn, Becquerel),
5) discovery that beta rays are negatively charged particles (Pierre Curie and Marie Skłodowska-Curie),
6) measurement of the e/m ratio for beta rays which yielded result very similar to that for cathode rays (Becquerel),
7) discovery by Lebedev of light pressure predicted by Maxwell's theory.

Albert Einstein

14 III 1879	Born in Ulm
1896-1900	Studied at the ETH Zürich
1902-1909	patent office in Bern
III 1905	*Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtpunkt*
V 1905	*Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen*
VI 1905	*Zur Elektrodynamik bewegter Körper*
IX 1905	*Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig*
1909-1914	Professor in Prague and Zürich
1914-1933	Professor in the Emperor Wilhelm Institute (Berlin)
XI 1915	*Die Grundlage der algemeinen Relativitätstheorie*
1916	*Zur Quantentheorie der Strahlung*
1922	Nobel Prize for physics (for 1921)
1924	*Quantentheorie des einatomigen idealen Gases*
from X 1933	Institute for Advanced Studies (Princeton)
1935	*Can Quantum-Mechanical Description... (EPR)*
18 IV 1955	Died in Princeton



Albert Einstein -1905

17 III — *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtpunkt*

11 V — *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen*

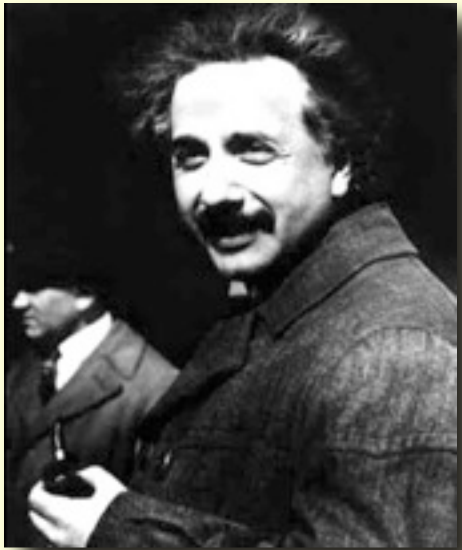
30 VI — *Zur Elektrodynamik bewegter Körper*

27 IX — *Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig*

Annalen der Physik **17**, 132-148 (1905)

6. ***Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt; von A. Einstein.***

Zwischen den theoretischen Vorstellungen, welche sich die Physiker über die Gase und andere ponderable Körper gebildet haben, und der Maxwellschen Theorie der elektromagnetischen Prozesse im sogenannten leeren Raume besteht ein tiefgreifender formaler Unterschied. Während wir uns nämlich den Zustand eines Körpers durch die Lagen und Geschwindigkeiten einer zwar sehr großen, jedoch endlichen Anzahl von Atomen und Elektronen für vollkommen bestimmt ansehen, bedienen wir uns zur Bestimmung des elektromagnetischen Zustandes eines Raumes kontinuierlicher räumlicher Funktionen, so daß also eine endliche Anzahl von Größen nicht als genügend anzusehen ist zur vollständigen Festlegung des elektromagnetischen Zustandes eines Raumes. Nach der



$E = h\nu - P$

On a Heuristic Point of View Concerning the Production and Transformation of Light
Annalen der Physik **17**, 132-148 (1905)

”A profound difference exists between the theoretical concepts that physicists have formed about gases and other ponderable bodies, and Maxwell’s theory of electromagnetic phenomena in so-called empty space. While we consider the state of a body to be completely determined by the positions and velocities of an indeed very large yet finite number of atoms and electrons, we make use of continuous spatial functions to determine the electromagnetic state of a volume of space, so that a finite number of quantities cannot be considered as sufficient for the complete determination of the electromagnetic state of space. According to Maxwell’s theory, energy is considered to be a continuous spatial function for all purely electromagnetic phenomena, hence also for light, whereas according to the present view of physicists, the energy of a ponderable body should be represented as a sum over the atoms and electrons.”

From Wien's formula for "black body radiation":
the dependence of the entropy of monochromatic radiation on the volume it occupies

$$S - S_0 = \frac{E}{\beta\nu} \ln\left(V \middle/ V_0 \right)$$

From Boltzmann's formula for the entropy of a gas:

$$S - S_0 = \frac{R}{N} \ln W = \frac{R}{N} \ln\left(V \middle/ V_0 \right)^n$$

Formal similarity of the two formulas is obvious

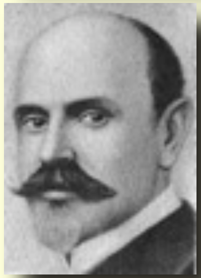
”Indeed, it seems to me that the observations of ‘black-body radiation’, photoluminescence, production of cathode rays by ultraviolet light, and other related phenomena associated with the emission or transformation of light appear more readily understood if one assumes that the energy of light is discontinuously distributed in space. According to the assumption considered here, in the propagation of a light ray emitted from a point source, the energy is not distributed continuously over ever-increasing volumes of space, but consists of a finite number of energy quanta localized at points of space that move without dividing, and can be absorbed or generated only as complete units...”

$$\Pi\varepsilon = \frac{R}{N}\beta\nu - P$$

”If the formula derived is correct, then Π, when plotted in Cartesian coordinates as a function of the frequency of the incident light, must give a straight light whose slope is independent of the nature of the substance under study. As far as I can tell, this conception of the photoelectric effect does not contradict its properties as observed by Mr. Lenard. If each energy quantum of the incident light transmits its energy to electrons, independently of all others, then the velocity distribution of the electrons, i.e., the nature of cathode rays produced, will be independent of the intensity of the incident light; on the other hand, under otherwise identical circumstances, the number of electrons leaving the body will be proportional to the intensity of the incident light.”

Photoelectric effect

1887 Heinrich Hertz (discovery)

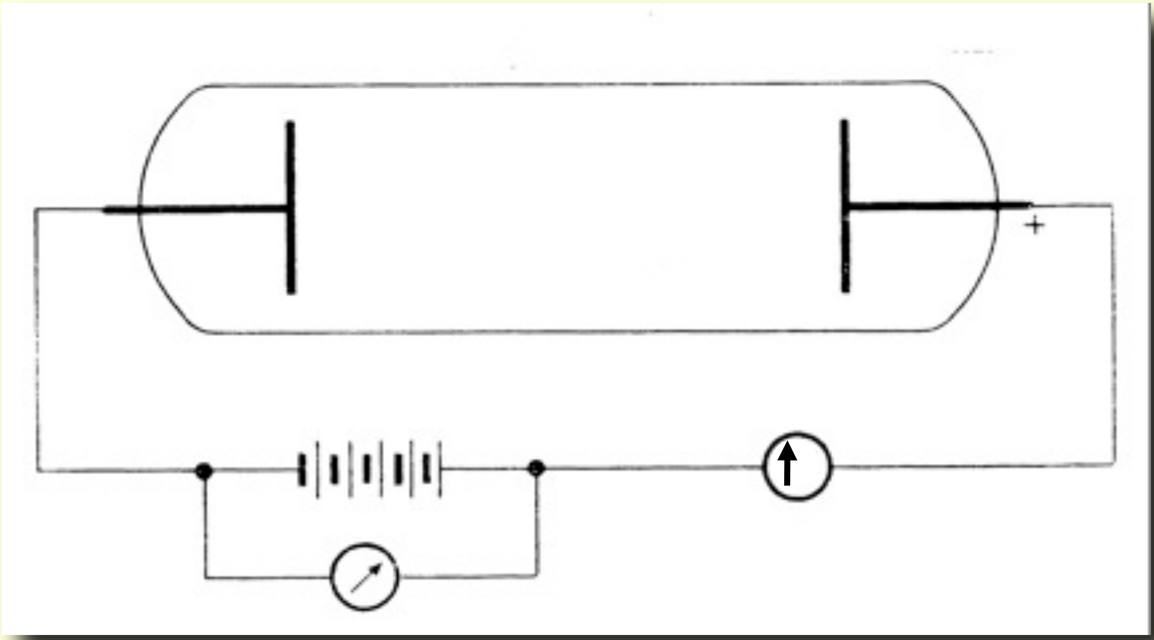


1888 Wilhelm Hallwachs – illuminated metal plate becomes positively charged

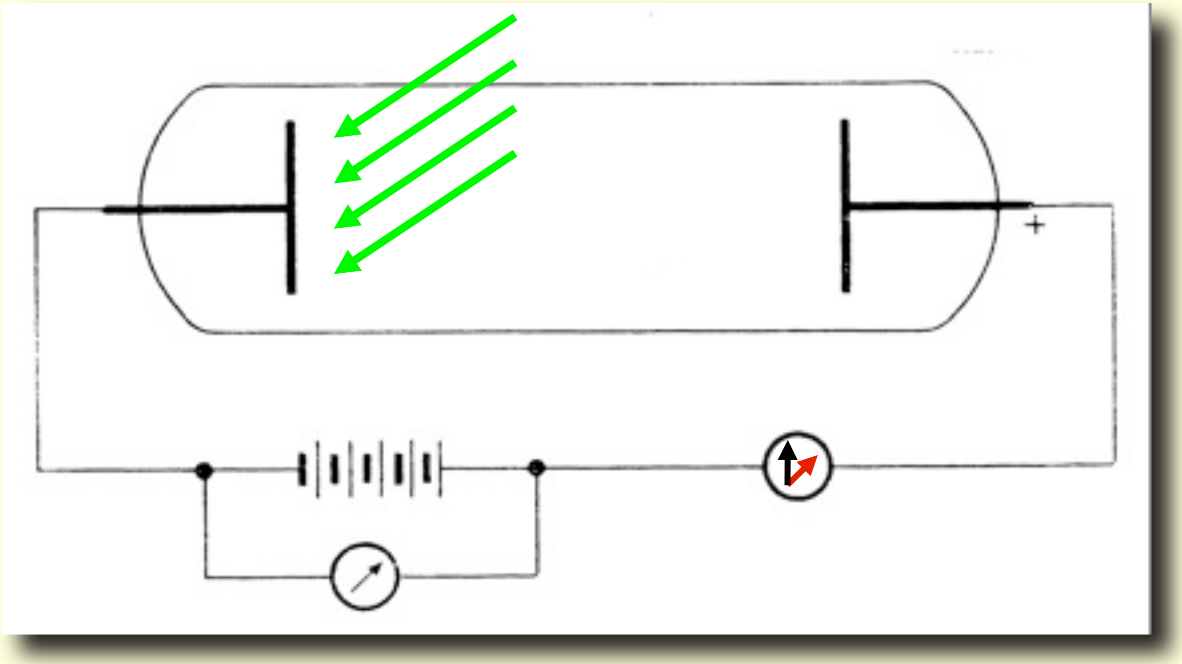
1888 Aleksandr Stoletow – light of wavelength above 285 nm does not give effect; first photocell constructed

1899-1902 Philipp Lenard – the energy of photoelectrons does not depend on the intensity of illumination

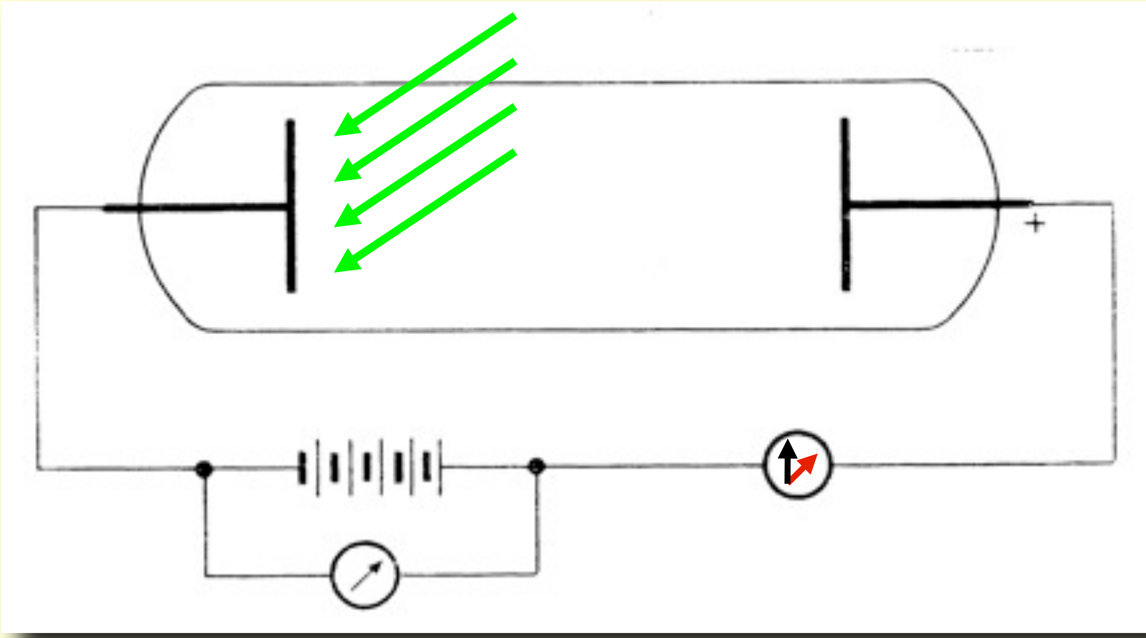
Photoelectric effect

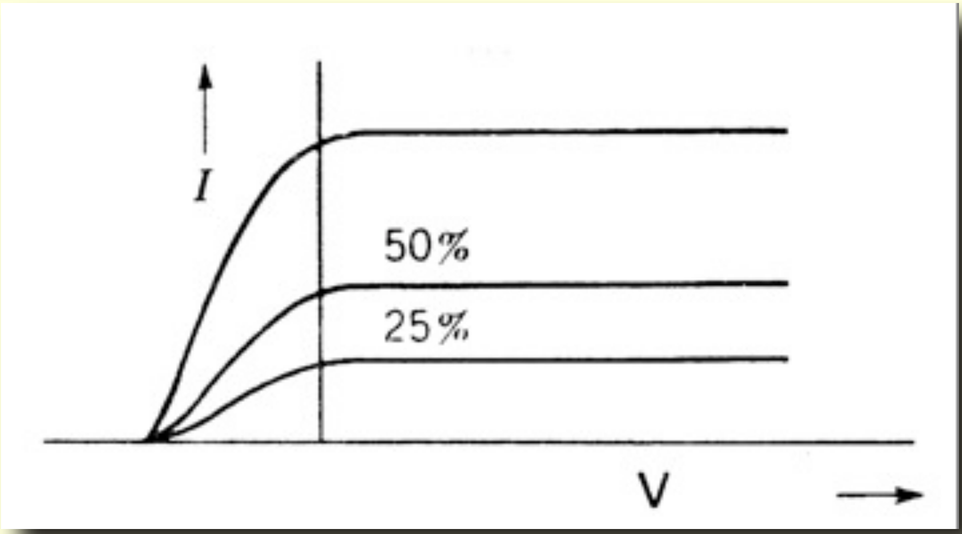


Photoelectric effect

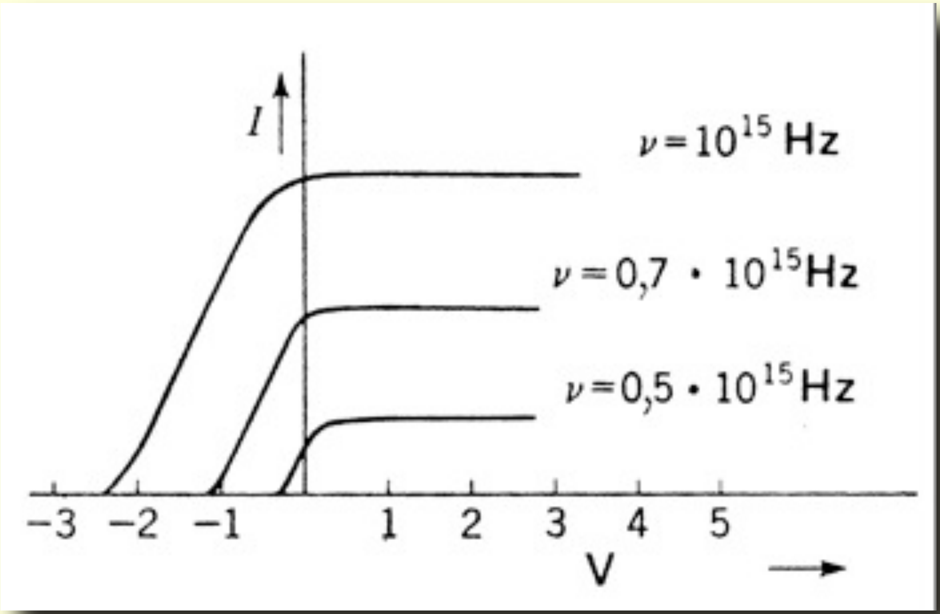


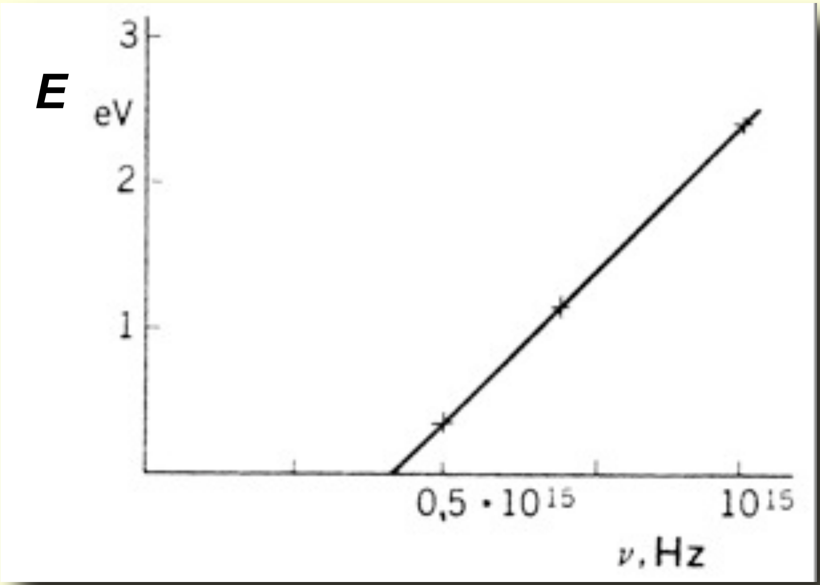
Photoelectric effect





Photoelectric effect





Lenard's experimental findings (1902)

Number of photoelectrons is proportional to the intensity of light

Energy of photoelectrons does not depend on the intensity of light

Energy of photoelectrons depends on the colour of incident light

Experimental studies of the photoeffect

Conflicting results of experimental attempts to determine the dependence of E on ν

1907 Ladenburg	$E = a\nu^{2}$
1911 Kunz	$E = a\nu^{2} - P$
1911 Lindemann	$E = a\nu^{2/3}$
1913 Cornelius	$E = a\nu^{3} - P$
1913 Richardson & Compton	$E = a\nu^{2} - P$
1913 Pohl & Pringsheim	$E = a\log\nu - P$

Many present textbooks of physics maintain that these experimental facts could not be in any way explained by classical physics

This is not correct!!!

Explanations of the photoelectric effect **(classical !)**

1902 Lenard – ”trigger” hypothesis

1910 Thomson – another ”trigger” hypothesis

1911 Sommerfeld – ”resonance emission” of electrons

1912 Richardson – ”evaporation” of electrons

In 1912 Richardson derived the formula $E = h\nu - P$ from classical considerations of an electron gas

”It appears therefore that the confirmation of the above equation... by experiment would not necessarily involve the acceptance of the unitary theory of light.”

Owen W. Richardson,
The Theory of Photoelectric Action,
Phil. Mag. **24**, 570 (1912)

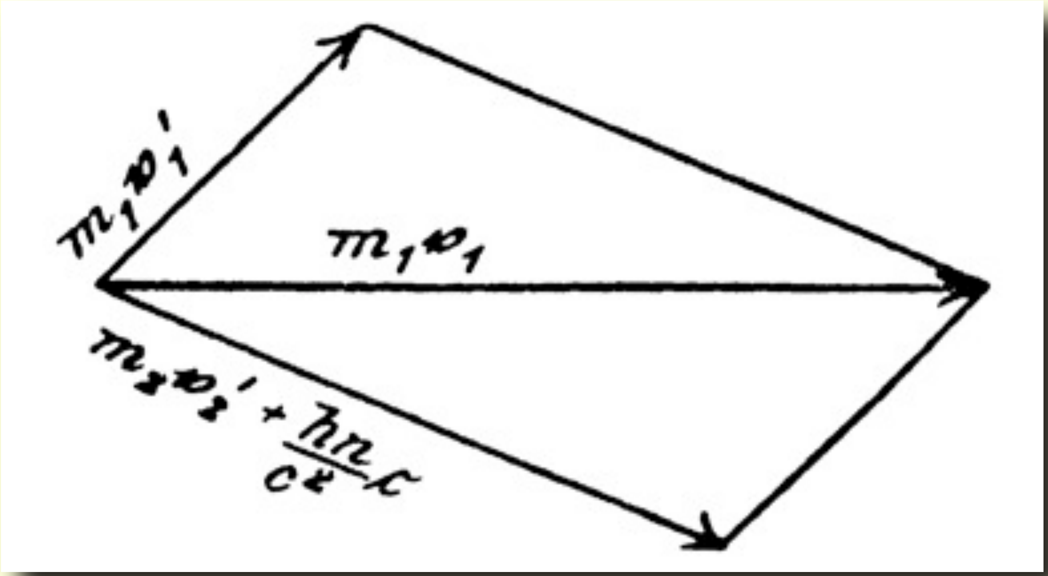
→ ”Einstein-Richardson equation”

Lorentz speculations on light quanta (1910)

- interference experiments of Lummer and Gehrcke which involved path differences up to roughly 80 cm proved that that distance represented a lower limit on the *longitudinal* extension of quanta
- The then largest telescope on Mt. Wilson had a mirror of 150 cm diameter – it represented a lower limit on the *lateral* extension of quanta

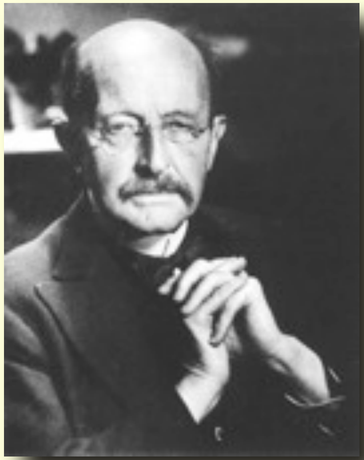
How could a quantum this monstrously large pass through the pupil of an eye without being subdivided?

In 1909 Johannes Stark first wrote explicitly *hν/c* for the momentum of a light quantum



Zur experimentellen Entscheidung zwischen Atherwellen und Lichtquanten-hypothese, Physikalische Zeitschr. **10**, 902 (1909)

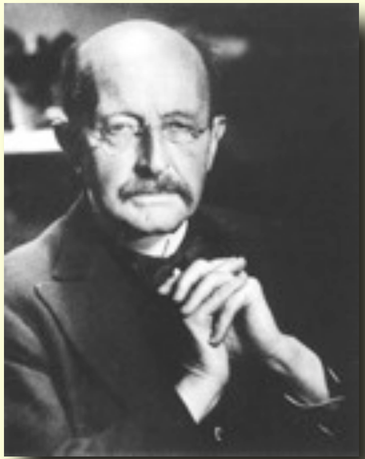
”If one considers the complete experimental confirmation which Maxwell’s electrodynamic theory obtained by means of the most delicate interference phenomena, and if one considers the extraordinary difficulties which its abandonment would entail for the entire theory of electric and magnetic phenomena, then one senses a certain repugnance in ruining its very fundamentals. For this reason, we shall leave aside the hypothesis of light quanta, especially since it is still quite early in the development of this notion.”



Max Planck, Solvay Congress 1911

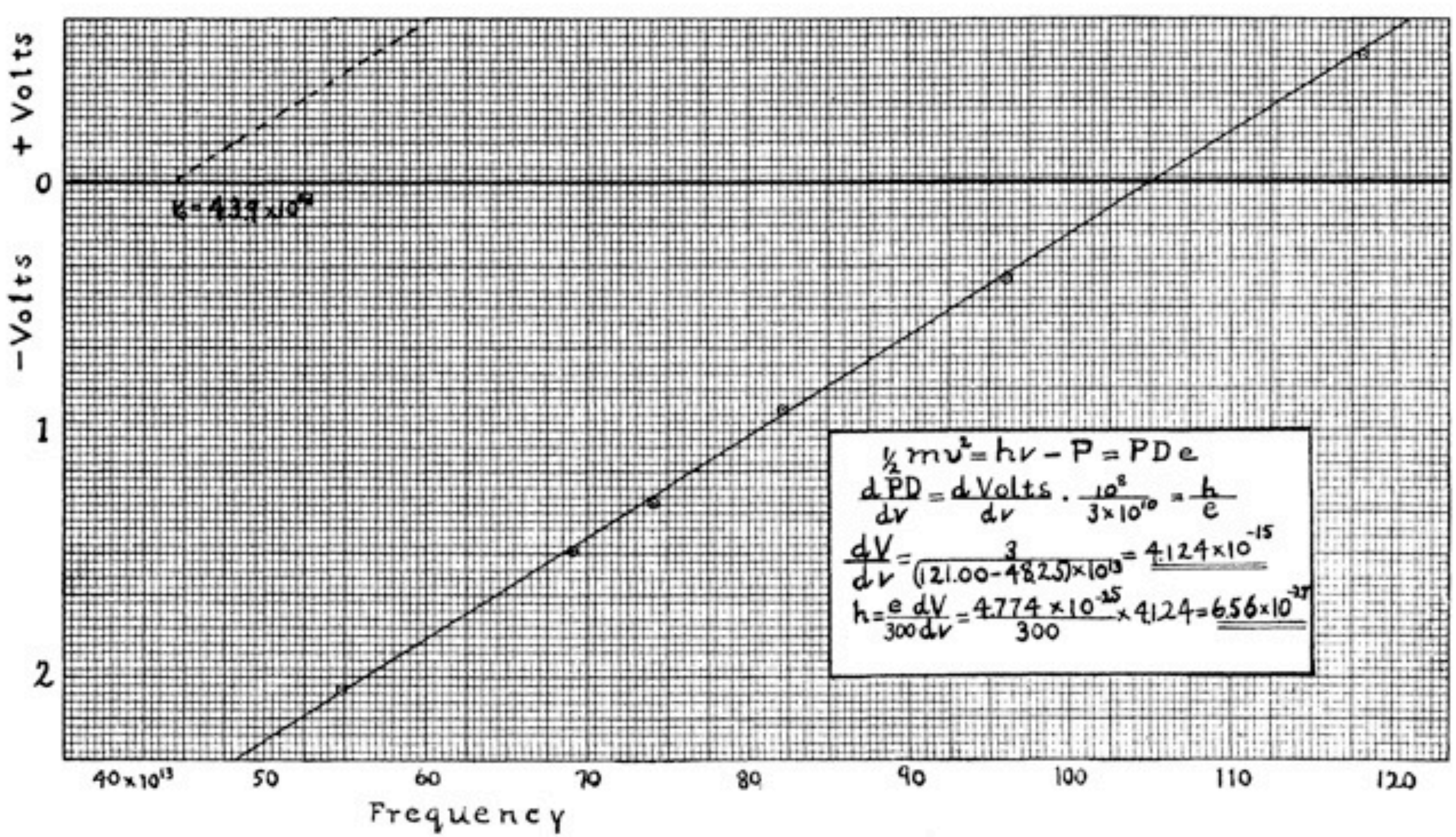
"It seems to me that we should renounce the supposition that the energy of the oscillator should be an integral multiple of the element of energy $\varepsilon = h\nu$ and we should accept, on the contrary, that the phenomenon of the absorption of free radiation is essentially continuous. From this point of view, one could preserve the fundamental hypothesis of quantum theory, by supposing that the emission of thermal radiation of frequency ν by an oscillator is discontinuous, and that energy can be emitted only in integral multiples of energy $\varepsilon = h\nu$."

Max Planck, Solvay Congress (1911)



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

Planck, Nernst, Rubens and Warburg, recommending Einstein for membership in the Prussian Academy of Sciences (1913)



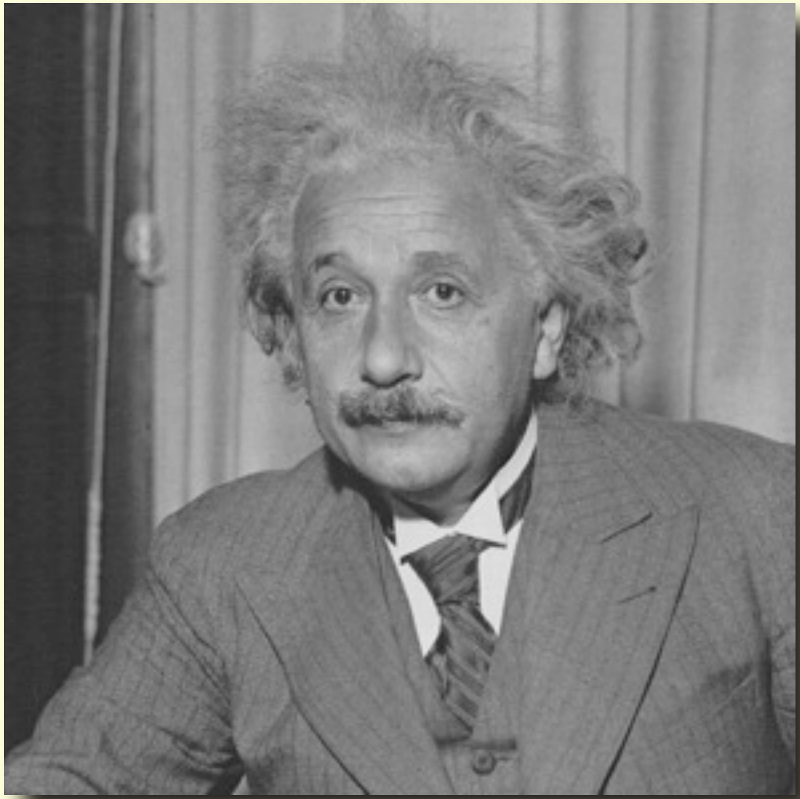
Millikan's results [*Phys. Rev.* **7**, *355* (1916)]

”It was in 1905 that Einstein made the first coupling of photo effects with any form of quantum theory by bringing forward the bold, not to say, the reckless, hypothesis of an electromagnetic light corpuscle of energy $h\nu$, which energy was transferred upon absorption to an electron. This hypothesis may well be called reckless first because an electromagnetic disturbance which remains localized in space seems a violation of the very conception of an electromagnetic disturbance, and second because it flies in the face of the thoroughly established facts of interference...

Despite the apparent complete success of the Einstein equation, the physical theory of which it was designed to be the symbolic expression is found so untenable that Einstein himself, I believe, no longer holds to it."

Robert Millikan, *Phys. Rev*. **7**, 355 (1916)

1922



The Nobel Prize in Physics
1921
was awarded to professor
Albert Einstein of Berlin
”for his services to Theoretical
Physics,
and especially for his
discovery of the laws of the
photoelectric effect”

”...a short step leads directly to the hypothesis of ‘light-quanta’, according to which all radiation consists of indivisible packets or ‘atoms’ of monochromatic light, each of which travels through space like a bullet from a rifle until it hits a material target by which it is completely absorbed. This view was put forward as a working hypothesis by Einstein in 1905, and at once enabled him to formulate the true law of photo-electric action.
In spite of this success it appears fairly certain that **the view must be regarded merely as a working hypothesis and not as a literal expression of actual fact.** Against the supposition that radiation actually travels in indivisible quanta must be set practically all the evidence of the undulatory theory of light, and, in particular, that of the phenomena of diffraction and interference...

The general opinion of physicists seem to be that the theory cannot be regarded as an expression of physical reality.”

Jeans, *The Dynamical Theory of Gases*, 4th ed., p. 378 **(1925)**

Albert Einstein -1905

17 III	*Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtpunkt*
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Brownian motion - the final proof of the kinetic theory of heat (and of atomic structure of matter)

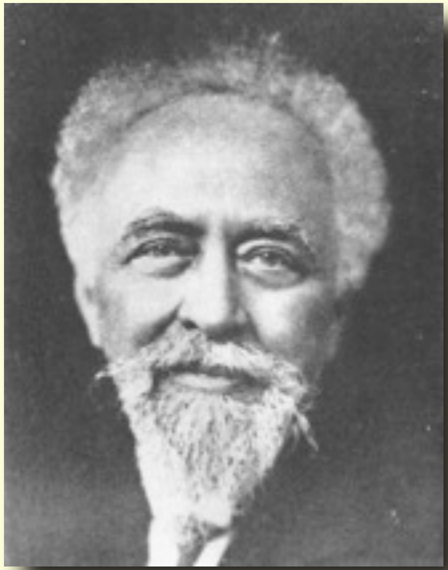
Albert Einstein and Marian Smoluchowski have proved independently that irregular movement of particles suspended in a liquid results from their bombardment by molecules of the liquid. They derived formula for the mean-square displacement of the suspended particle in a given direction (Einstein-Smoluchowski equation)

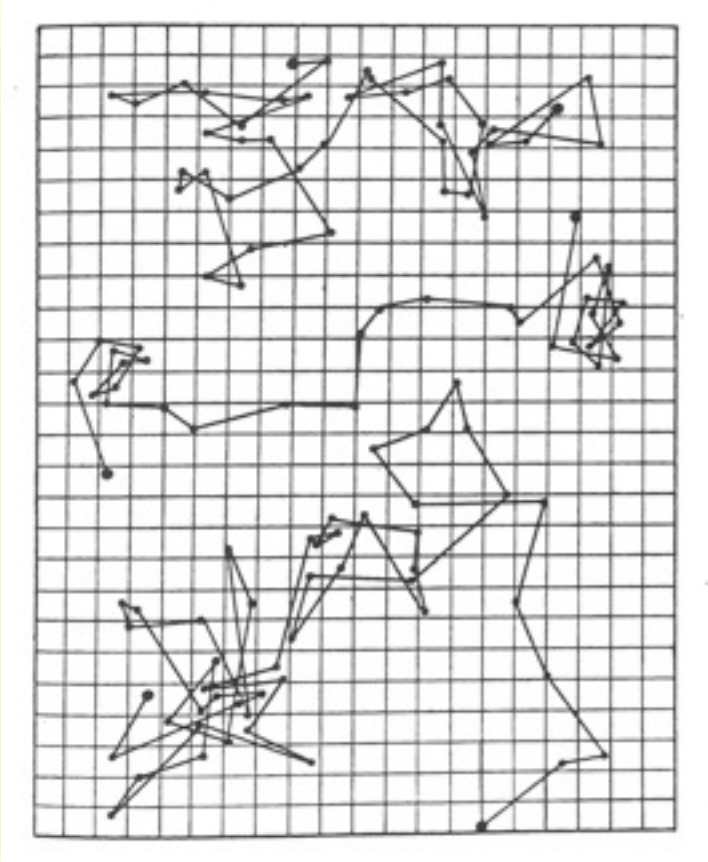
Annalen der Physik
17, 549 (1905)

Annalen der Physik
21, 755 (1906)

Einstein-Smoluchowski equation has been verified experimentally by Jean Perrin

who proved that the mean square displacement in a given direction is proportional to time; he also determined the Avogadro's number





In 1917 Smoluchowski was elected rector of the Jagiellonian University, but he did not take office; he contracted dysentery and died on September 5.

DIE NATURWISSENSCHAFTEN

Herausgegeben von

Dr. Arnold Berliner und Prof. Dr. August Pütter

Fünfter Jahrgang. 14. Dezember 1917. Heft 50.

Marian v. Smoluchowski.

Von *Albert Einstein*, Berlin.

Am 5. September wurde uns einer der feinsinnigsten zeitgenössischen Theoretiker jäh durch den Tod entrissen — *M. v. Smoluchowski*. Eine Dysenterieepidemie raffte in Krakau den erst 45-jährigen dahin.

Smoluchowskis wissenschaftliches Ringen galt der Molekulartheorie der Wärme. Insbesondere war sein Interesse auf diejenigen Konsequenzen der Molekularkinetik gerichtet, welche vom Standpunkt der klassischen Thermodynamik aus nicht verstanden werden können; denn er fühlte, daß nur von dieser Seite her der starke Widerstand zu überwinden war, den die Zeitgenossen am Ende des 19. Jahrhunderts der Molekulartheorie entgegenstellten.

Derselbe skeptische Geist, welcher die Elektrodynamik mächtig förderte, indem er sie von unzweckmäßigen mechanischen Bildern reinigte, hemmte zugleich die Entwicklung der Wärmelehre. Nachdem es den Physikern bewußt geworden war, daß eine Theorie allen Anforderungen der Klarheit und Vollständigkeit genügen könne, ohne auf Mechanik gegründet zu sein, lehnten sie auf allen Gebieten der Physik mechanische Theorien überhaupt ab. So begreift man, daß *Boltzmann* im Jahre 1898 im Vorwort zum zweiten Teil seiner „Vorlesungen über Gastheorie" bekümmert niederschrieb: „Es wäre meines Erachtens ein Schaden für die Wissenschaft, wenn die Gastheorie durch die augenblicklich herrschende, ihr feindselige Stimmung zeitweilig in Vergessenheit geriete, wie z. B. einst die Undulationstheorie durch die Autorität *Newtons*."

Schon in dieser Vorrede ist auf die im gleichen Jahre erschienene theoretische Arbeit *Smoluchowskis* über den Temperatursprung zwischen Wand und Gas bei der Wärmeleitung in sehr verdünnten Gasen hingewiesen. Diese von *Kundt* und *Warburg* schon 23 Jahre früher entdeckte Erscheinung lieferte in der Tat ein starkes Argument für die Molekularkinetik; denn wie sollte ein mit der Verdünnung des Gases wachsender Temperatursprung zwischen Wand und Gas ohne Zuhilfenahme des der klassischen Wärmelehre fremden Begriffes der freien Weglänge befriedigend gedeutet werden?

Um die Überzeugung der Gegner zu wandeln, bedurfte es aber eines noch schlagenderen Beweises. Die Existenz jenes Temperatursprunges war ohne die Kinetik zwar kaum zu begreifen, aber die Realität einer Wärmebewegung konnte aus diesem Phänomen nicht direkt gefolgert werden. Erst in den Jahren 1905—1906 gelangte die kinetische Wärmetheorie zu allgemeiner Anerkennung durch den Nachweis, daß die längst entdeckte Wimmelbewegung mikroskopisch kleiner, in Flüssigkeiten suspendierter Teilchen, die Brownsche Bewegung, durch diese Theorie quantitativ erklärt wird. *Smoluchowski* lieferte eine besonders schöne und anschauliche Theorie dieser Erscheinung, indem er von dem Äquipartitionssatz der Kinetik ausgeht. Dieser verlangt, daß ein Teilchen von 1 μ Durchmesser (und der Dichte des Wassers) sich in Flüssigkeit bei thermodynamischem Gleichgewicht mit einer mittleren Momentangeschwindigkeit von etwa 3 mm pro Sekunde bewegt; indem *Smoluchowski* quantitativ formuliert, daß diese Geschwindigkeit durch innere Reibung beständig vernichtet, durch unregelmäßige Molekularstöße immer wieder hergestellt wird, gelangt er zur Erklärung des Phänomens.

Durch die Erkenntnis vom Wesen der Brownschen Bewegung war plötzlich jeder Zweifel an der Richtigkeit der Boltzmannschen Auffassung der thermodynamischen Gesetze geschwunden. Es war klar, daß es ein thermodynamisches Gleichgewicht genau genommen überhaupt nicht gibt, daß vielmehr jedes dauernd sich selbst überlassene System um den Zustand des idealen thermodynamischen Gleichgewichtes in unregelmäßigem Wechsel pendelt. Da jedoch, wie die allgemeine Theorie zeigt, jene Schwankungen nur gering sind, so müssen sie sich unserer Beobachtung im allgemeinen entziehen. Es gelang aber *Smoluchowski* im Jahre 1908, eine zweite Gruppe von beobachtbaren Phänomenen zu finden, in welchen jene Schwankungen fast unmittelbar zur Wirkung kommen, nämlich bei der Opaleszenz von Gasen und von Flüssigkeiten in der Natur des kritischen Zustandes. Je kompressibler nämlich eine Substanz bzw. ein Mischungsbestandteil einer solchen ist, desto größer sind die örtlich-zeitlichen Schwankungen, welche die Dichte in unablässigem Wechsel infolge der Unregelmäßigkeit der Wärmebewegung erfahren muß; *Smoluchowski* erkannte, daß diese Schwankungen eine optische Trübung der Substanzen im Gefolge haben müssen, die sich auf Grund der allgemeinen Theorie berechnen läßt. Auch das schon von Lord *Rayleigh* erklärte Blau des Himmels gehört in diese Erscheinungsgruppe und beweist die Existenz räumlicher Dichteschwankungen in der Luft.

Smoluchowskis übriger wissenschaftlicher Arbeiten kann hier im einzelnen nicht gedacht werden. Es sei aber an die beiden vortreff-

PHYSIKALISCHE ZEITSCHRIFT

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INHALT:

Zum Andenken an Marian v. Smoluchowski. Von A. Sommerfeld. S. 533.

Originalmitteilungen:

A. Korn, Mechanische Theorien des elektromagnetischen Feldes. IV. S. 539.

M. v. Laue, Temperatur- und Dichteschwankungen. S. 542.

A. Hagenbach u. W. Frey, Spektroskopisches über elektrodenlose Ringentladung durch elektrische Schwingungen. S. 544.

M. Siegbahn u. W. Stenström, Über die Röntgenspektren der isotopischen Elemente. S. 547.

K. Uller, Grundlegung der Kinematik einer physikalischen Welle von elementarer Schwingungsform. III. S. 548.

Zusammenfassende Bearbeitungen:

G. Mie, Die Einsteinsche Gravitationstheorie und das Problem der Materie. S. 551.

Personalien. S. 556.

Angebote. S. 556.

Gesuche. S. 556.

Zum Andenken an Marian von Smoluchowski.

In Krakau verschied am 5. September d. J. nach kurzem Krankenlager an der Ruhr M. v. Smoluchowski. Wer seine glänzende wissenschaftliche Tätigkeit verfolgt hat, sah in ihm den eigentlichen Erben des Boltzmannschen Geistes der Naturbetrachtung. Mit dem jüngsten Aufschwunge der Atomistik wird sein Name für alle Zeiten verknüpft sein. Aus der Fülle erfolgreicher Arbeit ist er herausgerissen; niemand wird seine geistvolle Art ersetzen können.

M. Smoluchowski

Marian Ritter von Smolan-Smoluchowski wurde am 28. Mai 1872 in Vorder-Brühl bei Wien geboren als Sohn eines hohen Beamten in der Kanzlei des Kaisers Franz Joseph. In Wien besuchte er das Gymnasium und 1890—1894 die Universität, die ihn 1895 promovierte. Seine Lehrer waren Stefan und Exner. Boltzmann hat nur durch seine Schriften auf ihn gewirkt; eine nähere persönliche Berührung hat merkwürdigerweise nie stattgefunden. Enge Freundschaft verband ihn mit Hasenöhrl, der als unmittelbares Opfer des Krieges auf der Hochfläche von Lafraun 1915 gefallen ist; nicht nur wissenschaftliche Interessen, auch gleiche Liebe und Empfindung für Musik und treue Kameradschaft bei Bergtouren und beim Skisport führte beide zusammen.

Die Jahre nach seiner Promotion arbeitete Smoluchowski im Auslande: 1895/6 in Paris unter Lippmann, 1896/7 in Glasgow unter Lord Kelvin, 1897 in Berlin unter Warburg. Von seiner Lehrzeit in Glasgow zeugen einige Arbeiten (5), (6), (7)[1].

[1] Die Zahlen weisen auf das nachfolgende Verzeichnis hin.

Albert Einstein -1905

17 III	*Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtpunkt*
11 V	*Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen*
30 VI	*Zur Elektrodynamik bewegter Körper*
27 IX	*Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig*

3. *Zur Elektrodynamik bewegter Körper;*
von A. Einstein.

Daß die Elektrodynamik Maxwells — wie dieselbe gegenwärtig aufgefaßt zu werden pflegt — in ihrer Anwendung auf bewegte Körper zu Asymmetrien führt, welche den Phänomenen nicht anzuhaften scheinen, ist bekannt. Man denke z. B. an die elektrodynamische Wechselwirkung zwischen einem Magneten und einem Leiter. Das beobachtbare Phänomen hängt hier nur ab von der Relativbewegung von Leiter und Magnet, während nach der üblichen Auffassung die beiden Fälle, daß der eine oder der andere dieser Körper der bewegte sei, streng voneinander zu trennen sind. Bewegt sich nämlich der Magnet und ruht der Leiter, so entsteht in der Umgebung des Magneten ein elektrisches Feld von gewissem Energiewerte, welches an den Orten, wo sich Teile des Leiters befinden, einen Strom erzeugt. Ruht aber der Magnet und bewegt sich der Leiter, so entsteht in der Umgebung des Magneten kein elektrisches Feld, dagegen im Leiter eine elektromotorische Kraft, welcher an sich keine Energie entspricht, die aber — Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen vorausgesetzt — zu elektrischen Strömen von derselben Größe und demselben Verlaufe Veranlassung gibt, wie im ersten Falle die elektrischen Kräfte.

Beispiele ähnlicher Art, sowie die mißlungenen Versuche, eine Bewegung der Erde relativ zum „Lichtmedium" zu konstatieren, führen zu der Vermutung, daß dem Begriffe der absoluten Ruhe nicht nur in der Mechanik, sondern auch in der Elektrodynamik keine Eigenschaften der Erscheinungen entsprechen, sondern daß vielmehr für alle Koordinatensysteme, für welche die mechanischen Gleichungen gelten, auch die gleichen elektrodynamischen und optischen Gesetze gelten, wie dies für die Größen erster Ordnung bereits erwiesen ist. Wir wollen diese Vermutung (deren Inhalt im folgenden „Prinzip der Relativität" genannt werden wird) zur Voraussetzung erheben und außerdem die mit ihm nur scheinbar unverträgliche

Annalen der Physik **17**, 891-921 (1905)

On the electrodynamics of moving bodies,

Annalen der Physik **17**, 891-921 (1905)

”It is well known that Maxwell’s electrodynamics - as usually understood at present – when applied to moving bodies, leads to asymmetries that do not seem to be inherent in the phenomena. Take, for example, the electrodynamic interaction between a magnet and a conductor. The observable phenomenon here depends only on the relative motion of conductor and magnet, whereas the customary view draws a sharp distinction between the two cases, in which either the one or the other of the two bodies is in motion.”

”For if the magnet is in motion and the conductor is at rest, an electric field with a definite energy value results in the vicinity of the magnet that produces a current wherever parts of the conductor are located. But if the magnet is at rest while the conductor is moving, no electric field results in the vicinity of the magnet, but rather an electromotive force in the conductor, to which no energy per se corresponds, but which, assuming an equality of relative motion in the two cases, gives rise to electric currents of the same magnitude and the same course as those produced by the electric forces in the former case.”

”Examples of this sort, together with the unsuccessful attempts to detect a motion of the earth relative to the ”light medium”, lead to the conjecture that not only the phenomena of mechanics but also those of electrodynamics have no properties that correspond to the concept of absolute rest... We shall raise this conjecture (whose content will hereafter be called ”the principle of relativity”) to the status of a postulate and shall also introduce another postulate, which is only seemingly incompatible with it, namely that light always propagates with a definite velocity V that is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent electrodynamics of moving bodies based on Maxwell’s theory for bodies at rest.”

”The introduction of a “light ether” will prove to be superfluous, inasmuch as the view to be developed here will not require a “space at absolute rest” endowed with special properties, nor assign a velocity vector to a point in empty space where electromagnetic processes are taking place.

Like all electrodynamics, the theory to be developed here is based on the kinematics of a rigid body, since the assertions of any such theory have to do with the relations among rigid bodies (coordinate systems), clocks, and electromagnetic processes. Insufficient regard for this circumstance is at the root of the difficulties with which the electrodynamics of moving bodies currently has to contend.”

Einstein's paper *On the electrodynamics of moving bodies*:

A. Kinematic Part

1. Definition of simultaneity
2. On the relativity of length and time
3. Theory of transformations of coordinates and time from the rest system to a system in uniform translational motion relative to it
4. The physical meaning of the equations obtained as concerns moving rigid bodies and moving clocks
5. The addition theorem for velocities

B. Electrodynamical Part

6. Transformation of the Maxwell-Hertz equations for empty space. On the nature of the electromotive forces arising due to motion in a magnetic field
7. Theory of Doppler's principle and of aberration
8. Transformation of the energy of light rays. Theory of radiation pressure exerted on perfect mirrors
9. Transformation of the Maxwell-Hertz equations when convection currents are taken into account
10. Dynamics of the (slowly accelerated) electron

"After ten years of reflection such a principle resulted from a paradox upon which I had already hit at the age of sixteen: If I pursue a beam of light with the velocity *c* (velocity of light in a vacuum), I should observe such a beam of light as an electromagnetic field at rest though spatially oscillating. There seems to be no such thing, however, neither on the basis of experience nor according to Maxwell's equations. From the very beginning it appeared to me intuitively clear that, judged from the standpoint of such an observer, everything would have to happen according to the same laws as for an observer who, relative to the earth, was at rest. For how should the first observer know, or be able to determine, that he is in a state of fast uniform motion?"

Albert Einstein, *Autobiographisches*

”One sees that in this paradox the germ of the special relativity theory is already contained. Today everyone knows, of course, that all attempts to clarify this paradox satisfactorily were condemned to failure as long as the axiom of the absolute character of time, or of simultaneity, was rooted unrecognized in the unconscious. To recognize clearly this axiom and its arbitrary character already implies the essentials of the solution of the problem. "

Albert Einstein, *Autobiographisches*

Special relativity theory (1905)

Einstein's postulates

1. The laws of physics are the same for all observers, who are in a uniform rectilinear motion with respect to each other

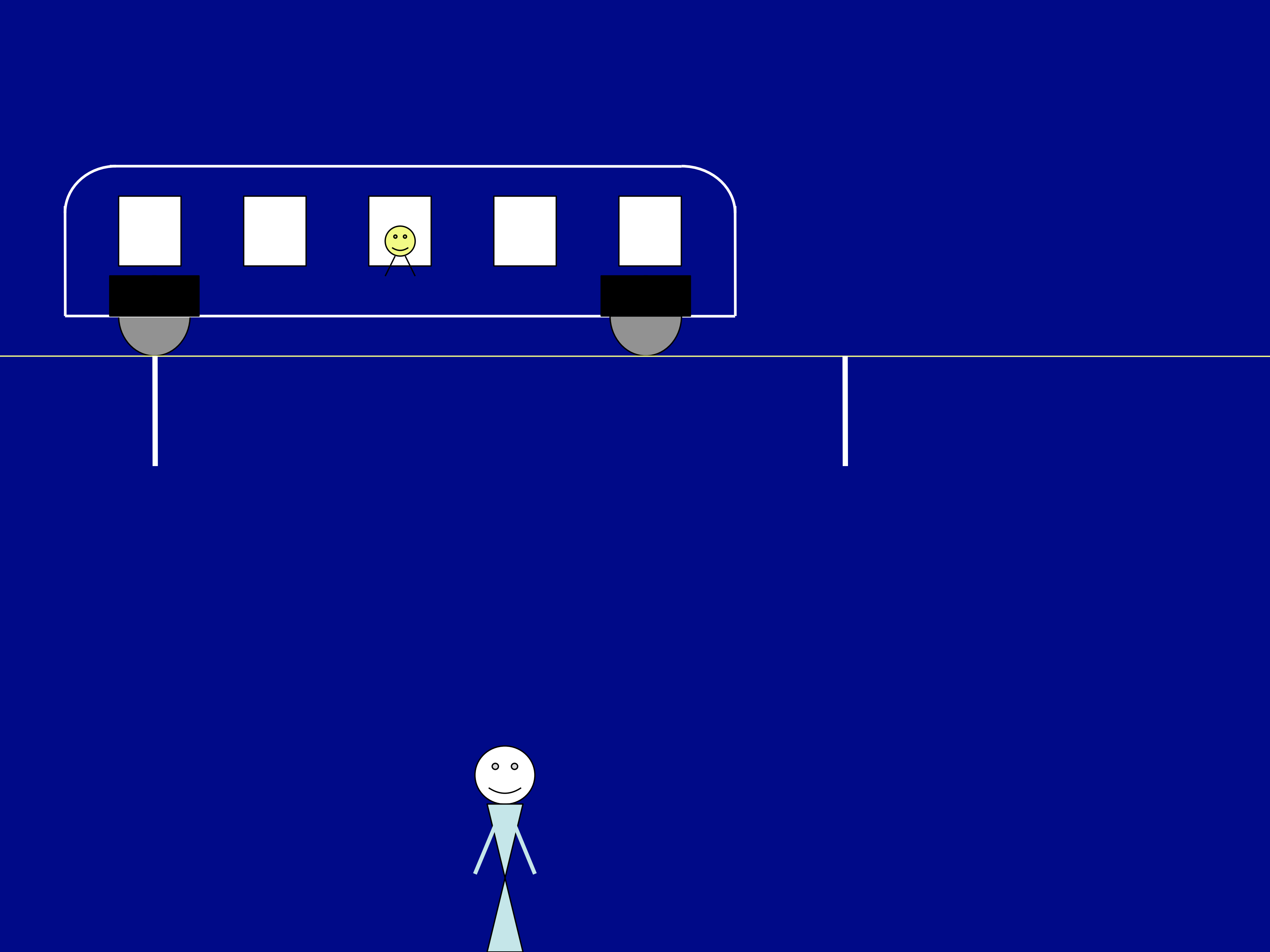
2. Velocity of light in a vacuum *c* is constant

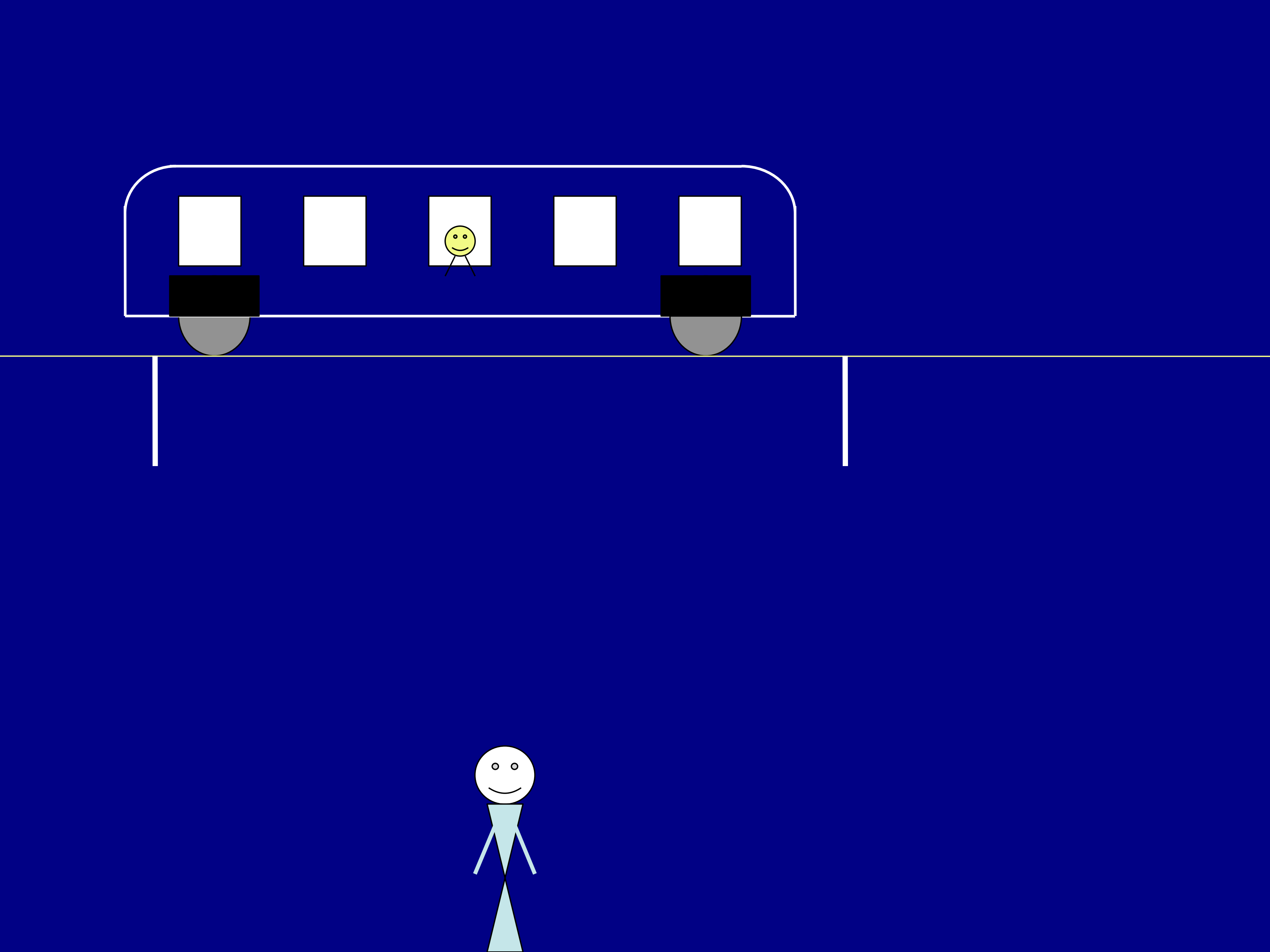
Very strange conclusions of Einstein’s theory

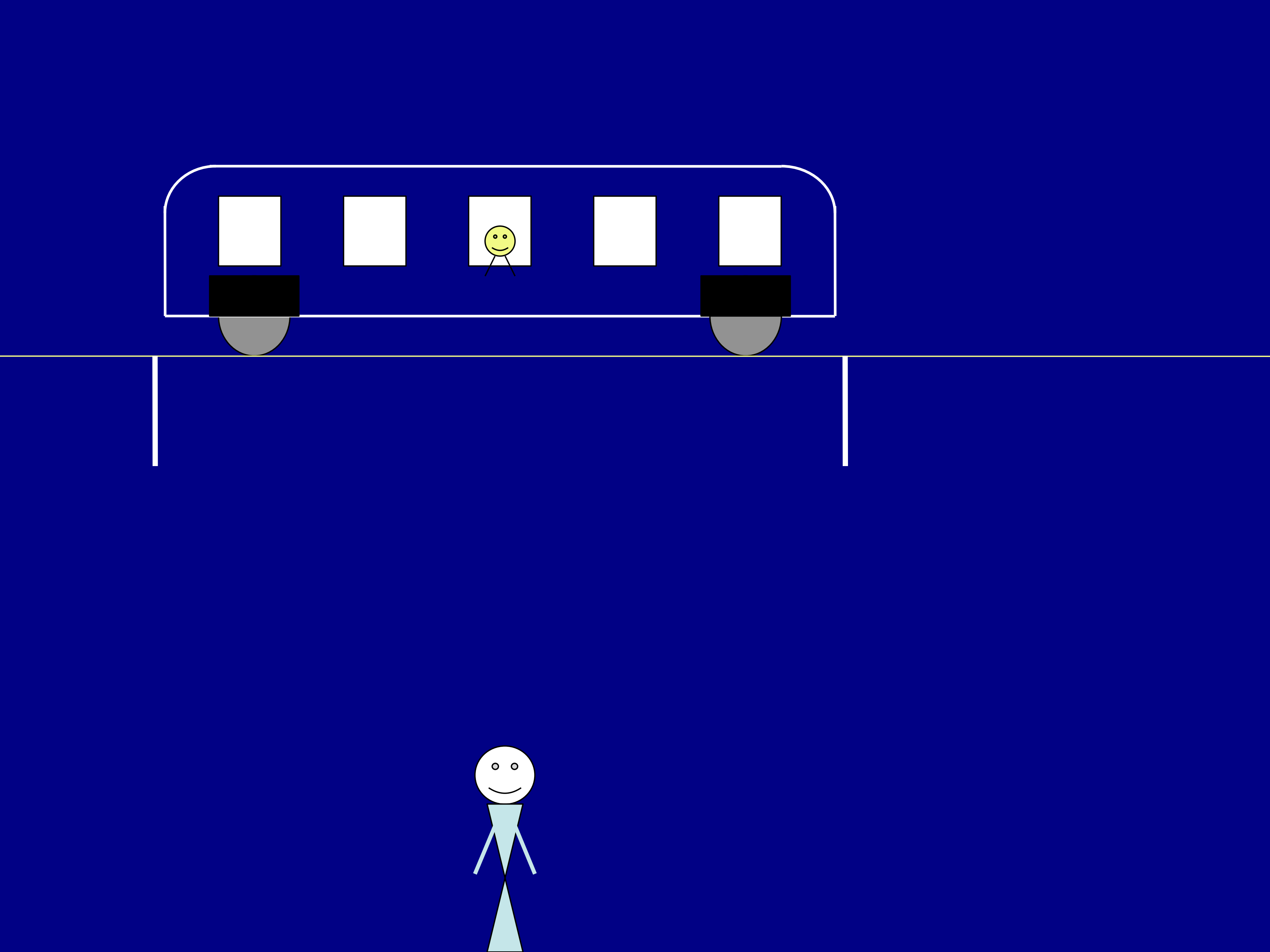
Time and space are not absolute

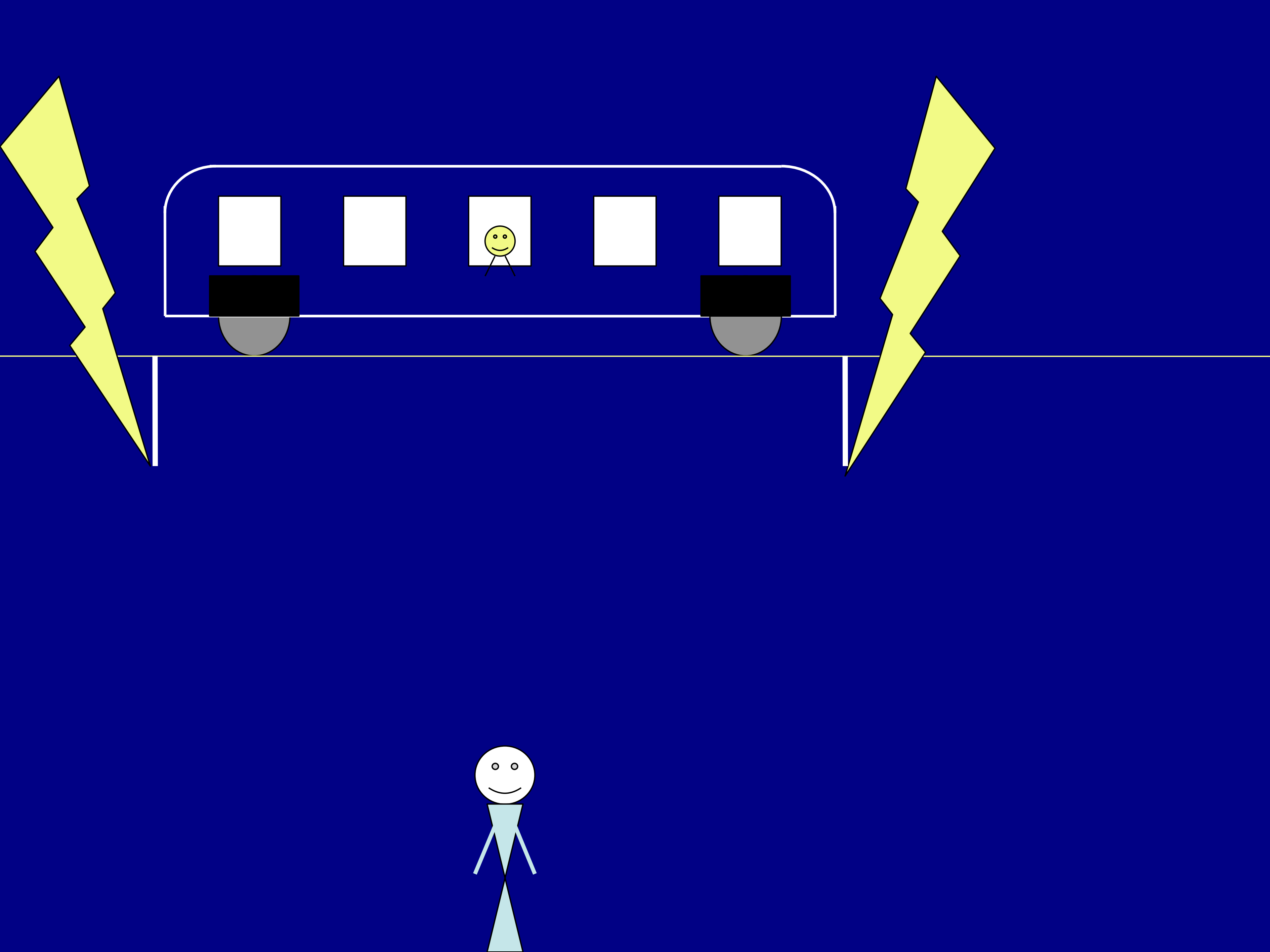
Simultaneity of events is not absolute

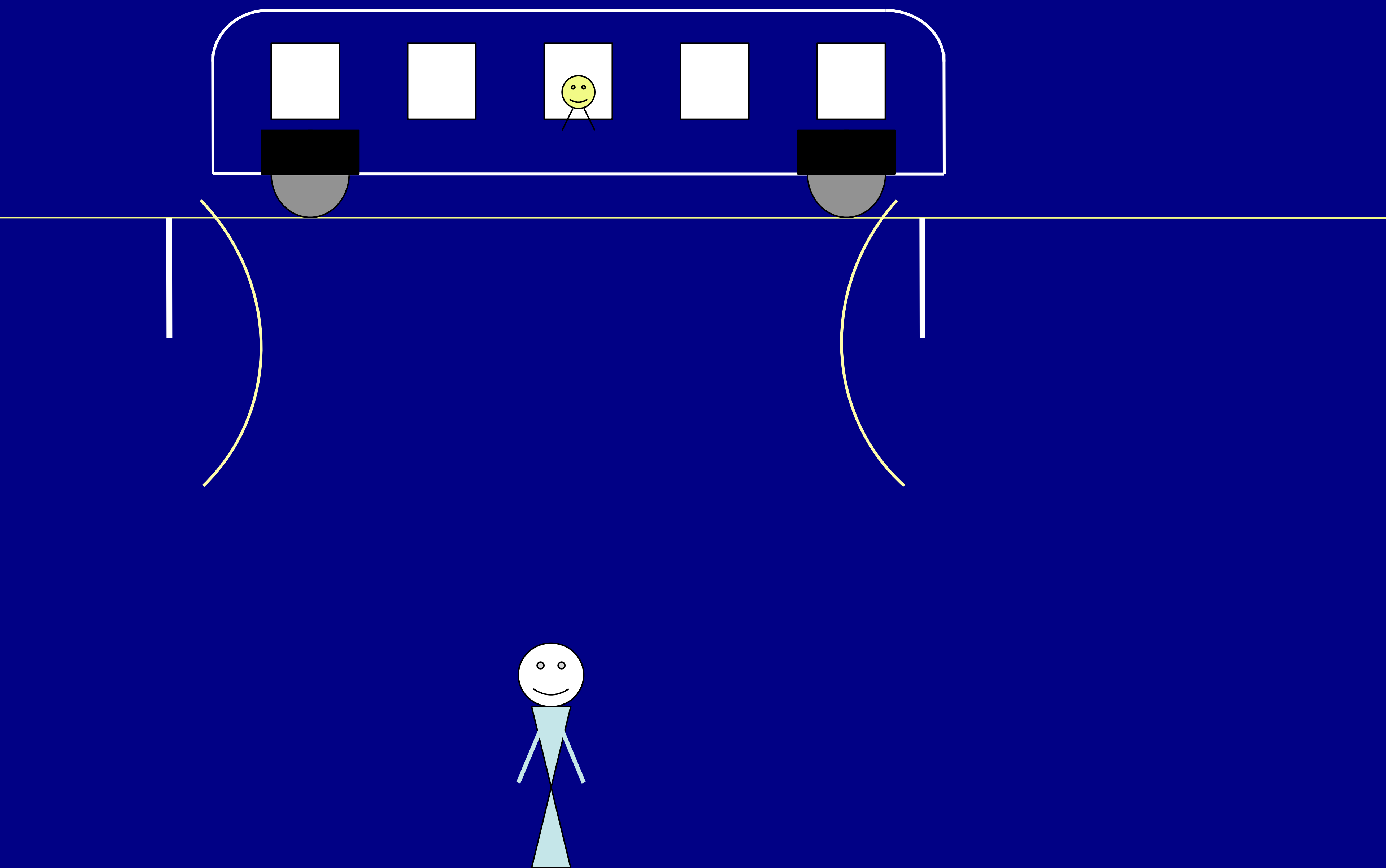
May be illustrated by the following animation of ”Einstein’s train”

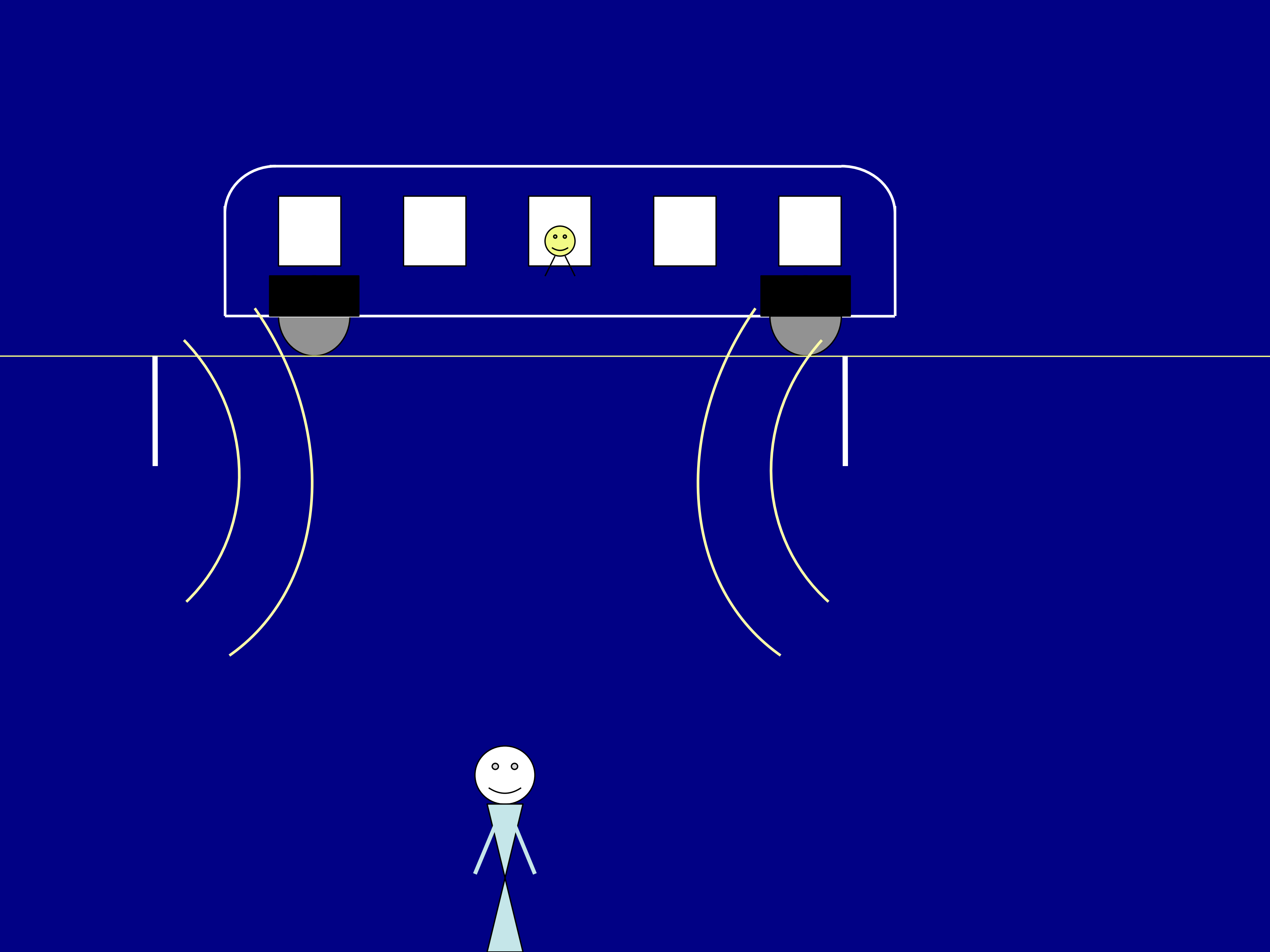


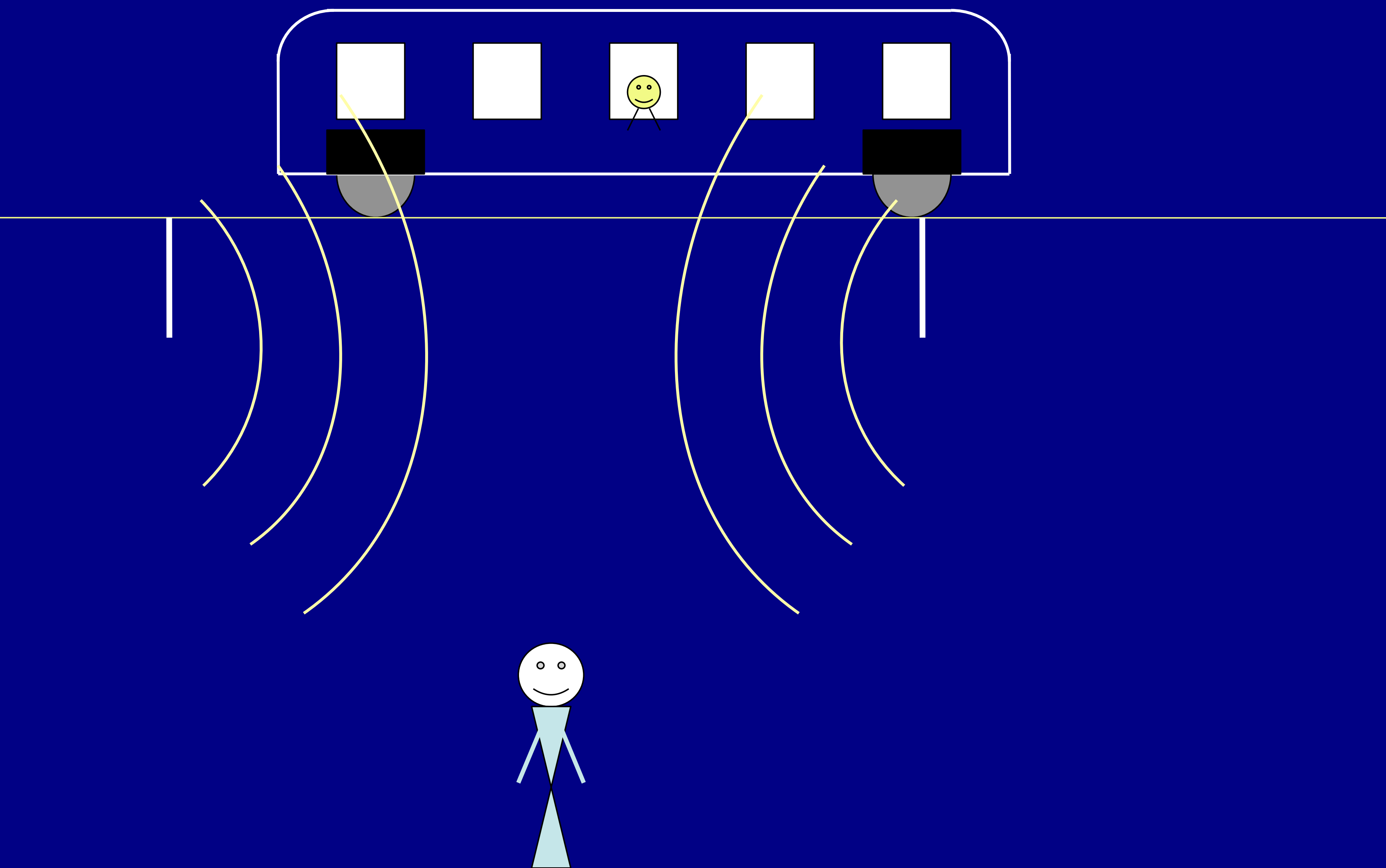


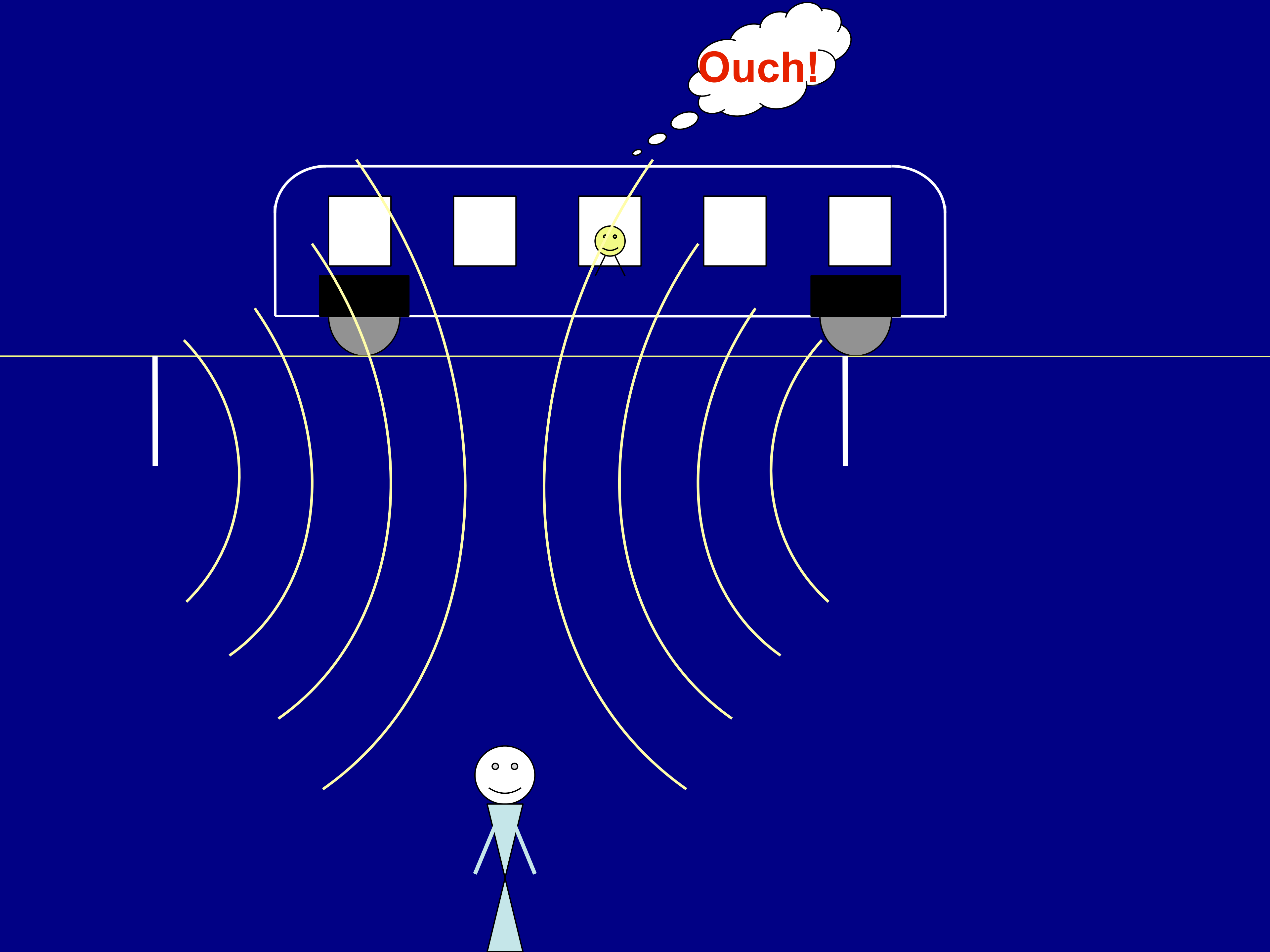


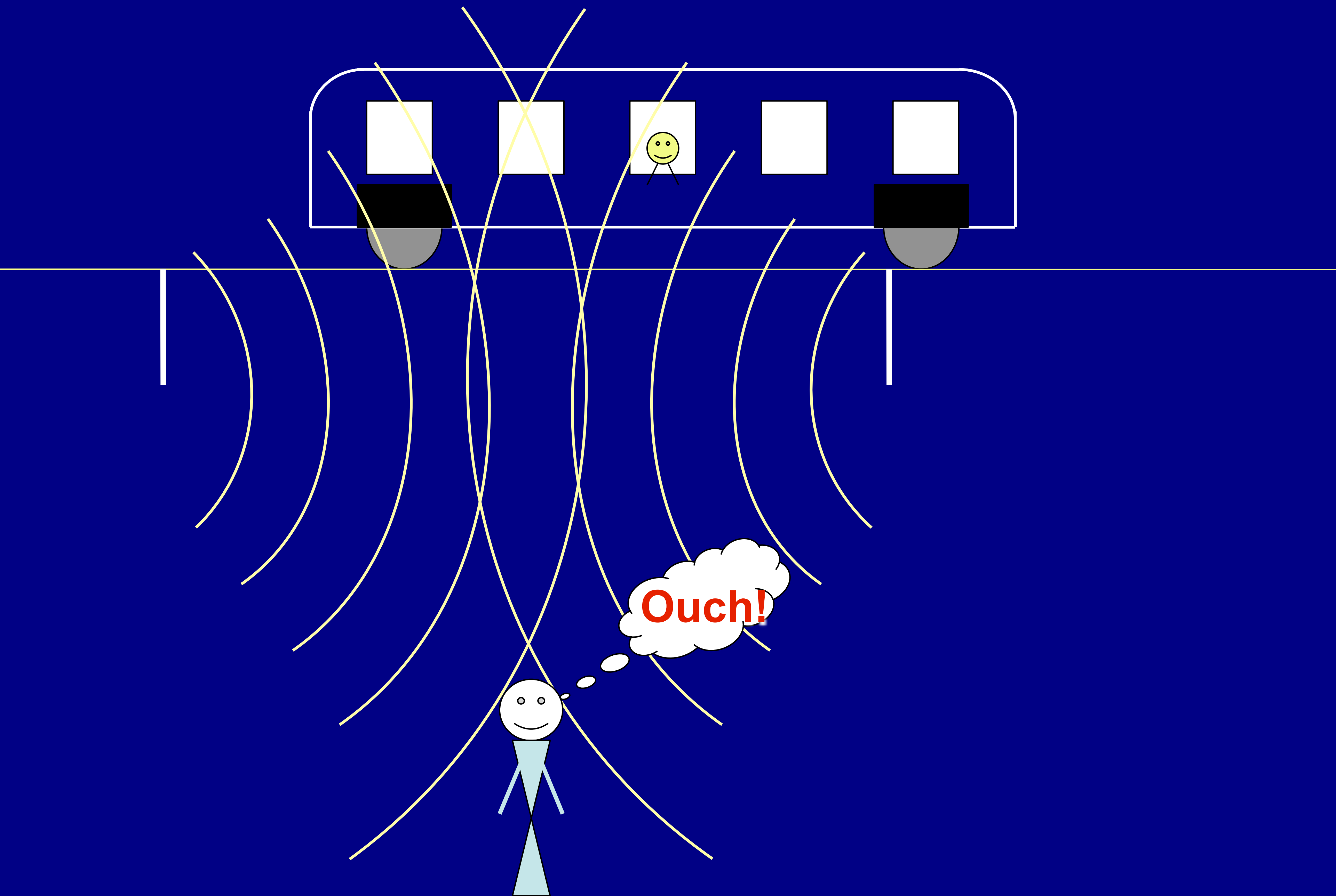




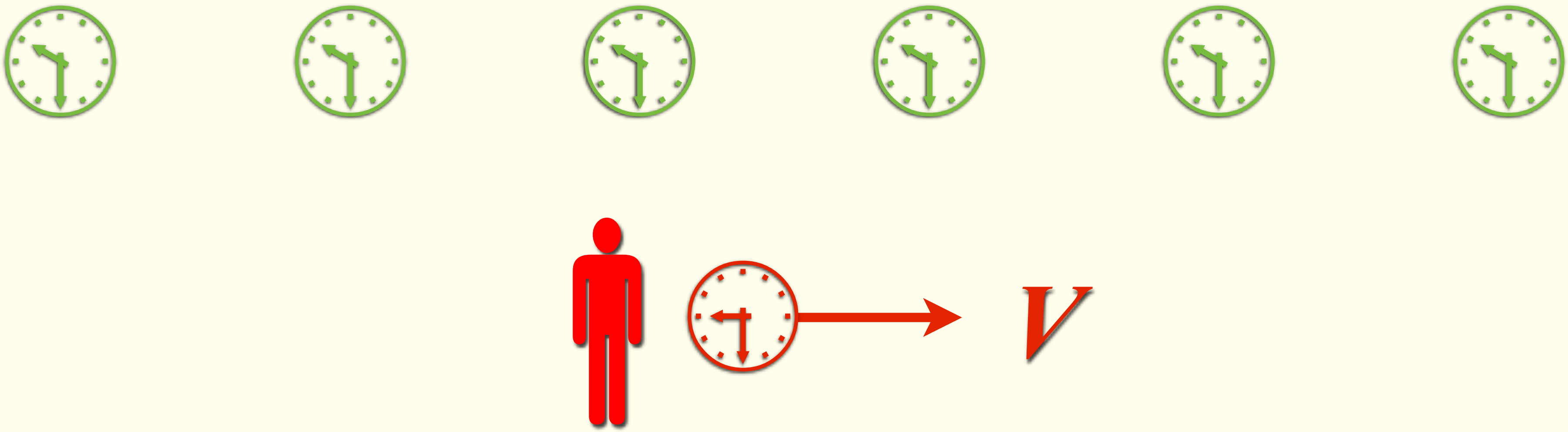





Ouch!

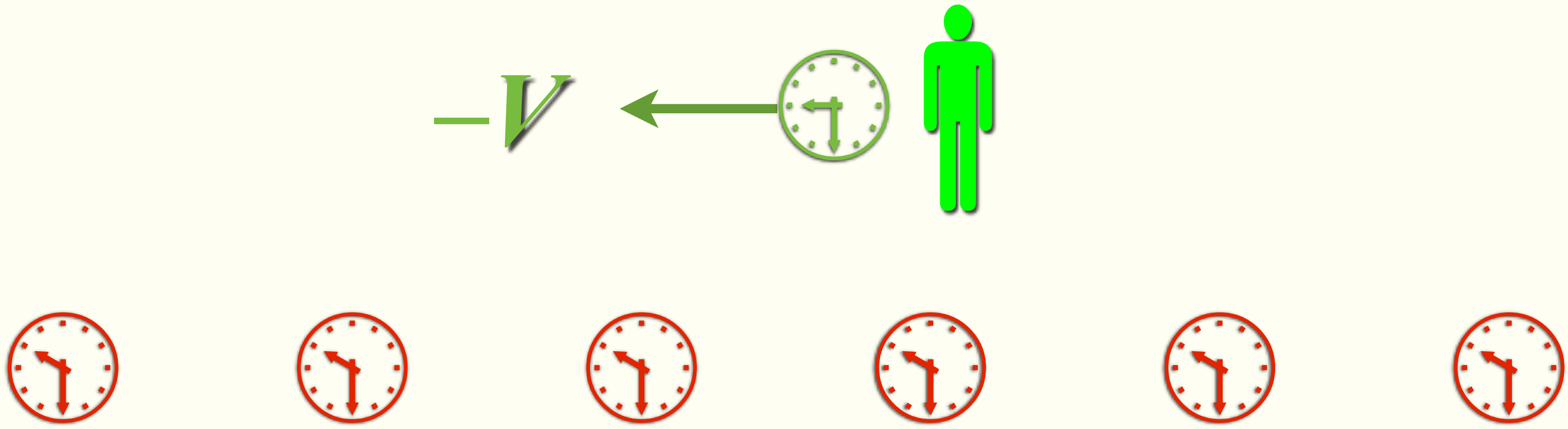

Ouch!

Time passes differently for various observers



When Mister **RED**
compares his **clock** with **clocks** synchronized
in the **GREEN system**, which he passes
with velocity V, he finds that
his clock is running late

The same is observed by Mister **GREEN**
who compares his **clock**
with **clocks** synchronized
in the **RED system**, which he passes
with velocity $-V$



In both cases a single clock in one system is being compared <u>with a</u> <u>series of clocks</u> synchronized in the other system

The effect of time dilation is **reciprocal** as are other effects of kinematic origin

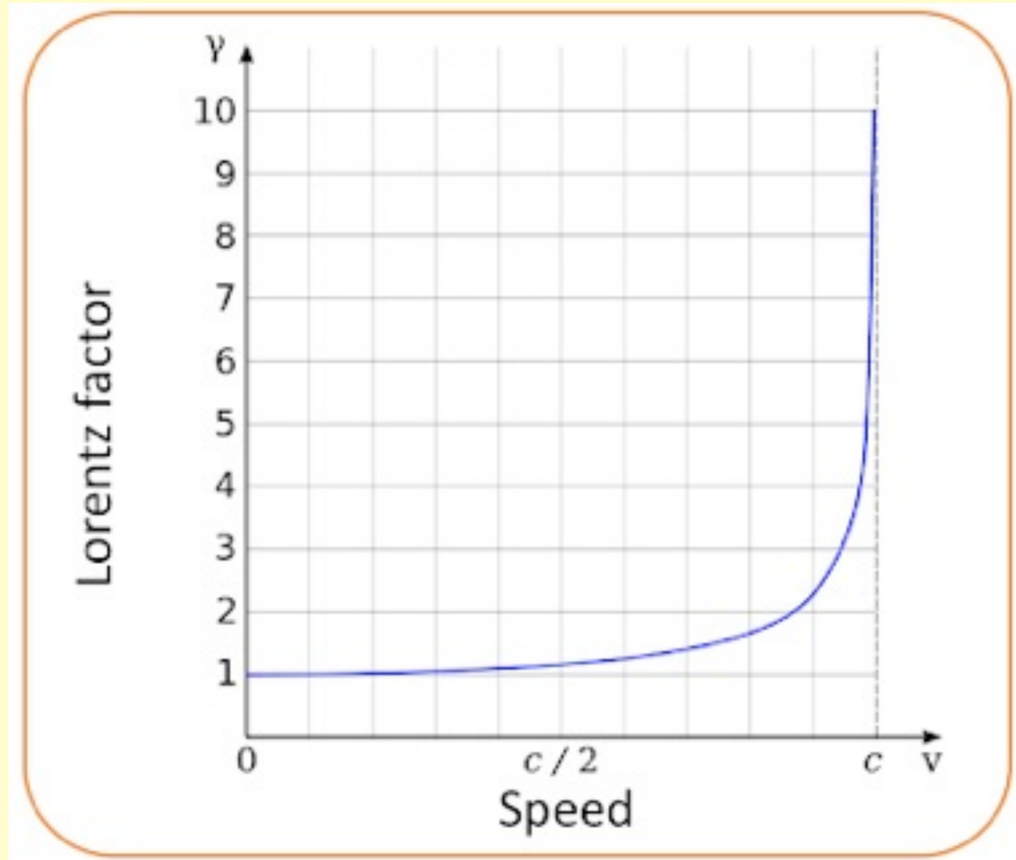
Kinematic dilation of time
is of the order of $(v/c)^2$
and is hard to be noticed
in everyday life

For the „Apollo" ships *v*/*c* ≈ 0,0001

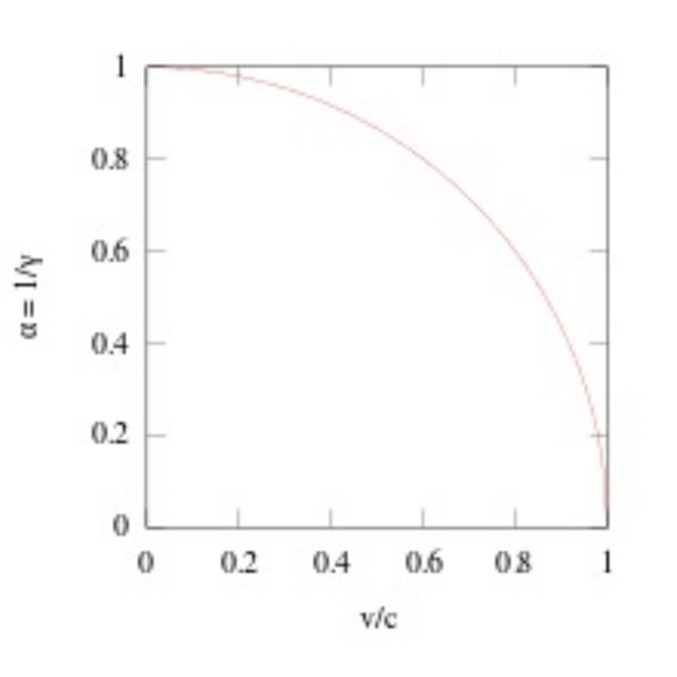
This would give a difference in clocks of
about 0,00000001

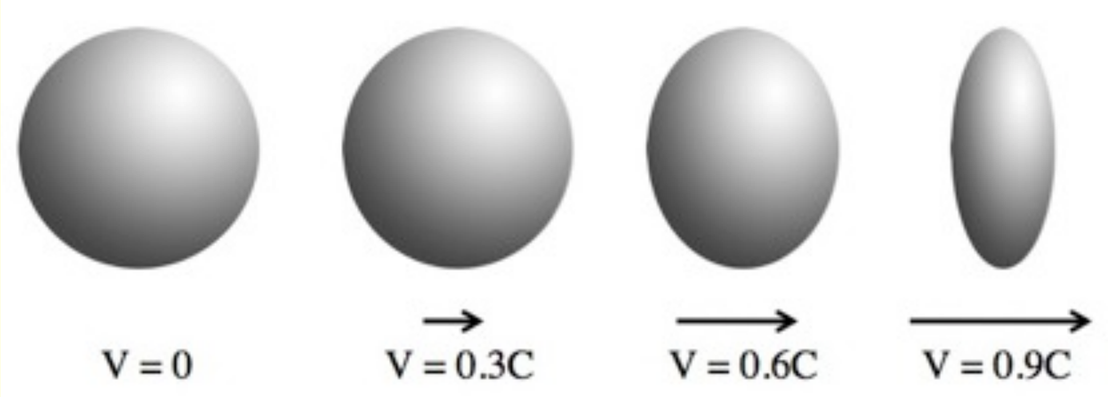
Lorentz factor γ

$$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$



Lorentz factor γ





Length contraction

Experimental checks of kinematic time dilation almost always involve also time dilation predicted by the general theory of relativity

$\rightarrow$ part 4

Albert Einstein -1905

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Does the inertia of a body depend on its energy content?

Annalen der Physik **18**, 639-641 (1905)

"If a body emits the energy *L* in the form of radiation, its mass decreases by L/V^2. Here it is obviously inessential that the energy taken from the body turns into radiant energy, so we are led to the more general conclusion: The mass of a body is a measure of its energy content; if the energy changes by L, the mass changes in the same sense by $L/9 \cdot 10^{20}$ if the energy is measured in ergs and the mass in grams.

It is not excluded that it will prove possible to test this theory using bodies whose energy content is variable to a high degree (e.g. radium salts). If the theory agrees with the facts, then radiation carries inertia between emitting and absorbing bodies."

$$E = mc^2$$

Checked experimentally firstly in 1932

Newest check (2005) has precision of 0,00004%

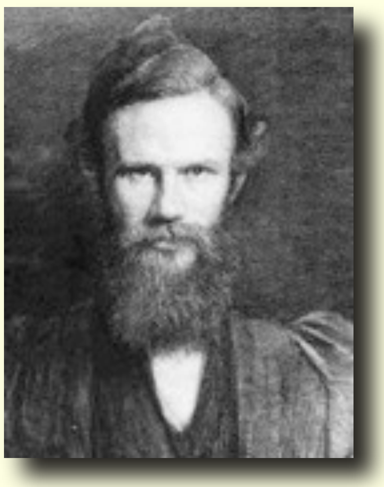
Einstein, Lorentz, Poincaré, and the others

Edmund Whittaker – *A History of the Theories of Aether and Electricity*,
Vol. 2, The Modern Theories 1900-1926 (1954)

Chapter 2. The relativity theory of Poincaré and Lorentz

”In the autumn of the same year, in the same volume of the *Annalen der Physik* as his paper on the Brownian motion, Einstein published a paper which set forth the relativity theory of Poincaré and Lorentz with some amplifications, and which attracted much attention.”

Hendrik Lorentz



George FitzGerald

In order to explain the result of Michelson-Morley experiment Lorentz assumed that in motion through the **elastic immobile ether**
the dimension of a body in the direction of motion is contracted by a factor
$1 - 2v^2/c^2$ (1892)
$(1 - v^2/c^2)^{1/2}$ (1895)

In 1899 Lorentz analysed the change of time scale in a transformation (‘local time’). In the same year FitzGerald independently conceived the idea of contraction.
Contraction was regarded as **real and resulting from the properties of molecular forces**.

(hence the name FitzGerald-Lorentz contraction)

In 1904 Lorentz, developing his electron hypothesis, proved the invariance of Maxwell’s equations with respect of postulated [Lorentz] transformation

In 1900 Larmor announced his electron theory of matter (”*Aether and Matter*”). He used ”Lorentz transformation” for *x, y, z, t* and derived the FitzGerald-Lorentz contraction. He also gave transformations of electric and magnetic fields.
He stressed that the results are exact only to order v^2/c^2

Joseph Larmor

Baseless internet claims

Einstein's relativity paper of 1905 did not contain anything new, because the formulae of relativistic transformation [Lorentz transformation] were already used by Voigt in 1887, and then by Lorentz in 1892-1904 and Larmor in 1900, while the relativity principle was given by Poincaré in 1904.

Einstein is only a plagiarist?!

Woldemar Voigt

In 1887 Voigt published his results on the propagation of deformation waves in an elastic medium. He found that the results are invariant under the transformation

$$x_1' = x_1 - vt$$
$$y_1' = y_1(1 - v^2/\omega^2)$$
$$z_1' = z_1(1 - v^2/\omega^2)$$
$$t' = t - vx_1/\omega^2$$

(ω phase velocity)

It is easily seen that Voigt's formulae are <u>different</u> from Lorentz transformation

Electromagnetic theory of matter

Electromagnetic theory of matter

Wilhelm Wien

"Über die Möglichkeit einer elektromagnetischen Begründung der Mechanik" (1900)

Electromagnetic theory of matter

Max Abraham

Max Abraham was one of the chief propagators of a program of replacing the laws of newtonian mechanics by the laws of Maxwell's electrodynamics, which were to be recognized as fundamental laws of physics. All mass was believed to be of electromagnetic origin

Electromagnetic theory of matter

Walter Kaufmann

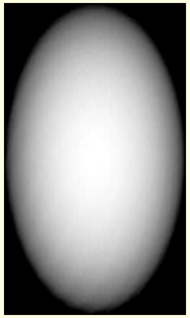
In 1901 Kaufmann began measurements of *e/m* ratio of beta rays from radium chloride. The mass of electrons was indeed found to depend on their velocity

”It is now confidently affirmed that the mass of the electron is wholly of the nature of electromagnetic inertia, and hence, as Abraham (1902), utilizing Kaufmann’s data (1902) on the increase of electromagnetic mass with the velocity of the corpuscle, has shown, the Lagrangian equations of motion may be recast in an electromagnetic form.”

Carl Barus, *The progress of physics in the nineteenth century*, St. Louis Congress (1904)

Three models of the electron

Abraham (1902) – charge distributed uniformely over the surface of a **rigid** sphere



Lorentz (1904) – charge distributed uniformely over the surface of a sphere, **which undergoes deformation** in motion through the ether

Bucherer (1904), Langevin (1905) – charge distributed uniformely over the surface of a sphere which is deformed in motion through the ether, such that **its volume remains constant**

Electron mass as function of its velocity

$$m = m_0 \psi(\beta)$$

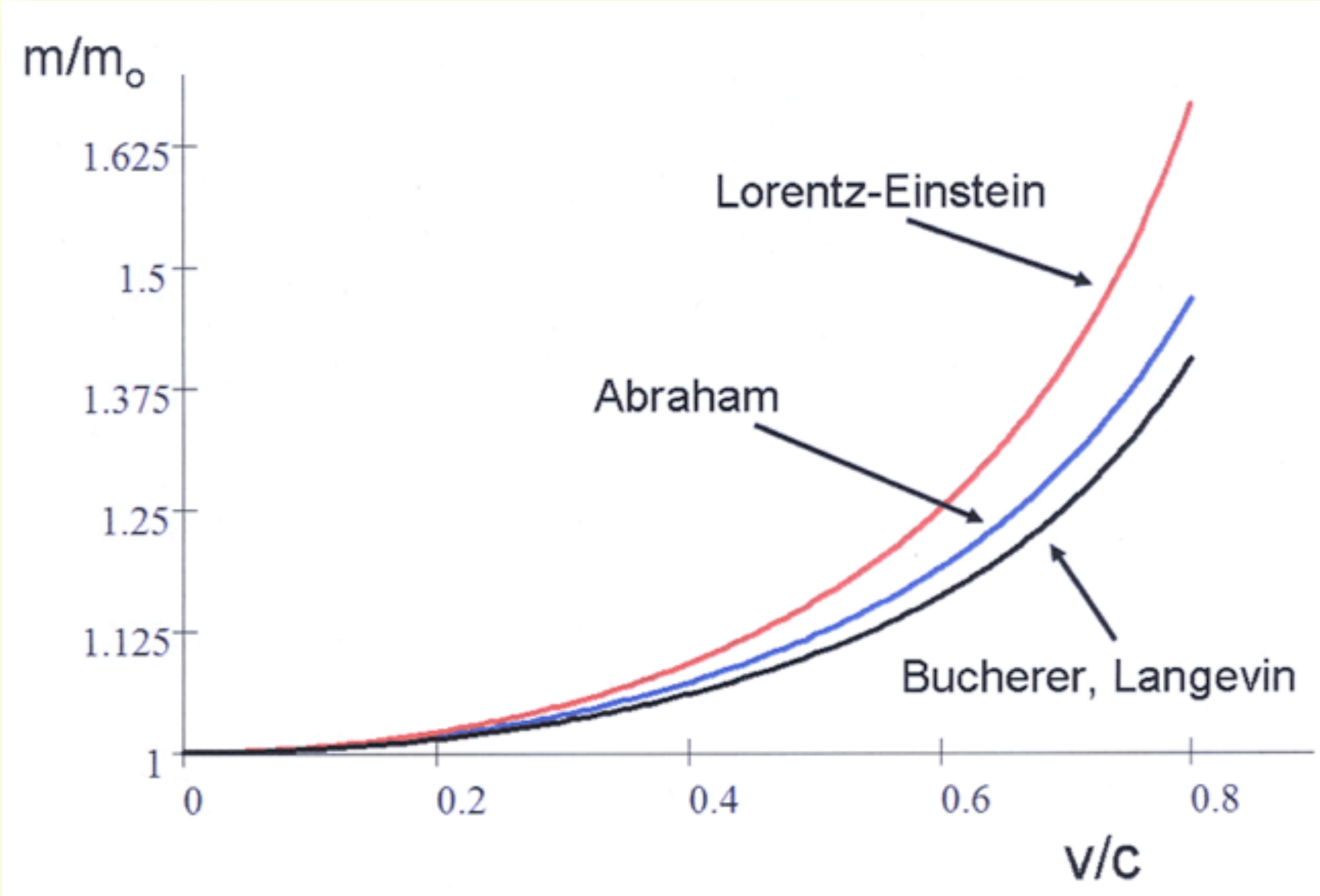
Abraham $$\psi(\beta) \cong 1 + \frac{2}{5}\beta^2 + \frac{9}{35}\beta^4 + \ldots$$

Lorentz $$\psi(\beta) \cong 1 + \frac{1}{2}\beta^2 + \frac{3}{8}\beta^4 + \ldots$$

Bucherer $$\psi(\beta) \cong 1 + \frac{1}{3}\beta^2 + \frac{2}{9}\beta^4 + ..$$

The formula obtained by Einstein in special relativity was **formally identical** to that of Lorentz, although derived under completely different assumptions

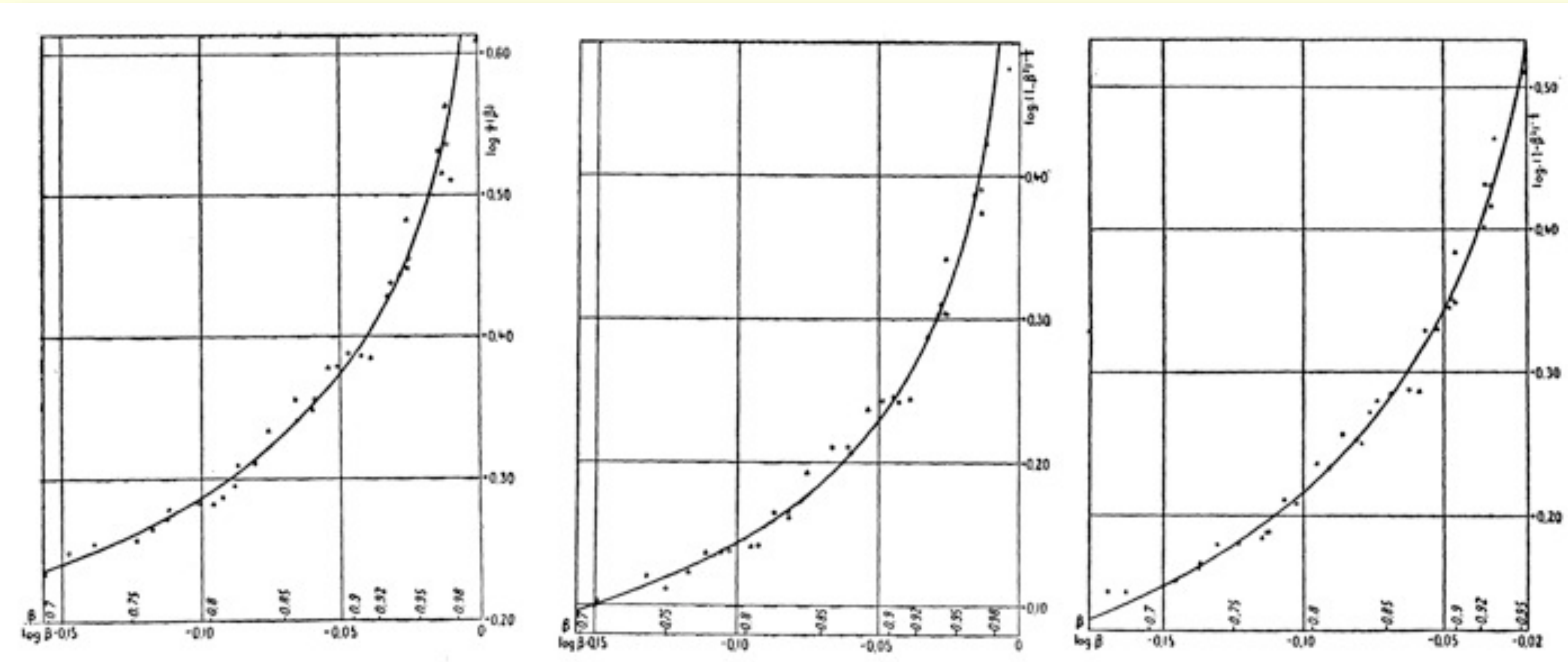
Electron mass as function of its velocity



Hermann Minkowski

”Approaching Maxwell’s equations with the concept of the rigid electron seems to me the same thing as going to a concert with your ears stopped up with cotton wool”

Paul Langevin – *The relation of physics of electrons to other branches of science* (St. Louis Congress, 1904)



Abraham **Bucherer, Langevin** **Lorentz, Einstein**

”The experimental points... given by Kaufmann... correspond equally well with the three theoretical curves.”

The British Association for the Advancement of Science meeting at Winnipeg (Canada) in August, 1909

Ernest Rutherford

Address of the President of the Mathematical and Physical Section, *Science* **30**, 289-302 (1909)

”Experiment has shown that the apparent mass of the electron varies with its speed, and, by comparison of theory with experiment, it has been concluded that the mass of the electron is entirely electrical in origin and that there is no necessity to assume a material nucleus on which the electrical charge is distributed.”

Electromagnetic theory of matter

Kaufmann (1902-1905) – **Abraham's model confirmed**

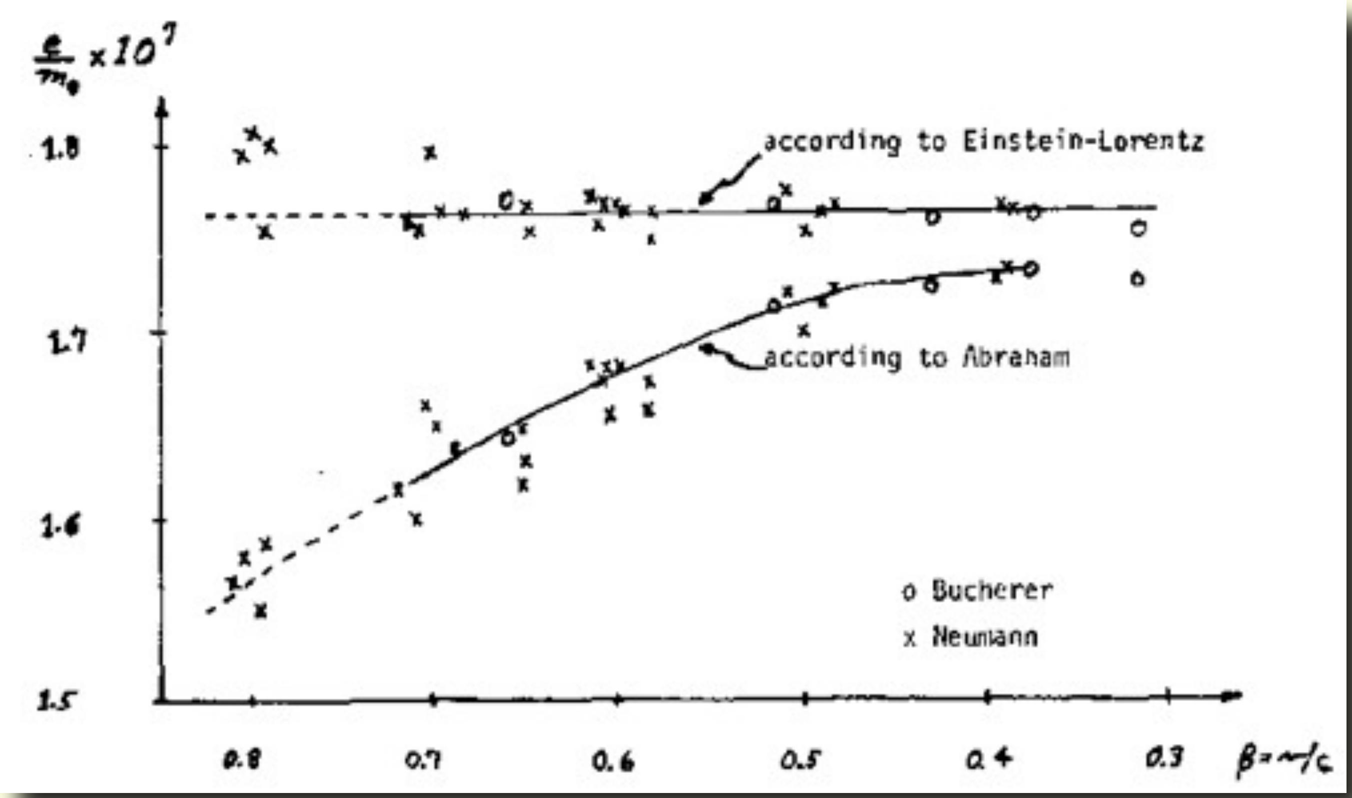
> ”The results ...speak against the correctness of Lorentz's, and also consequently of Einstein's, fundamental hypothesis. If one considers this hypothesis as thereby refuted, then the attempt to base the whole of physics, including electrodynamics and optics, upon the principle of relative motion is also a failure.”
> Kaufmann, *Sitzungsber. K. Preuss. Akad. Wiss.* 2, 949 (1905)

Bestelmeyer (1907) – **all models equally good**

Bucherer (1909) – **Lorentz's model better**

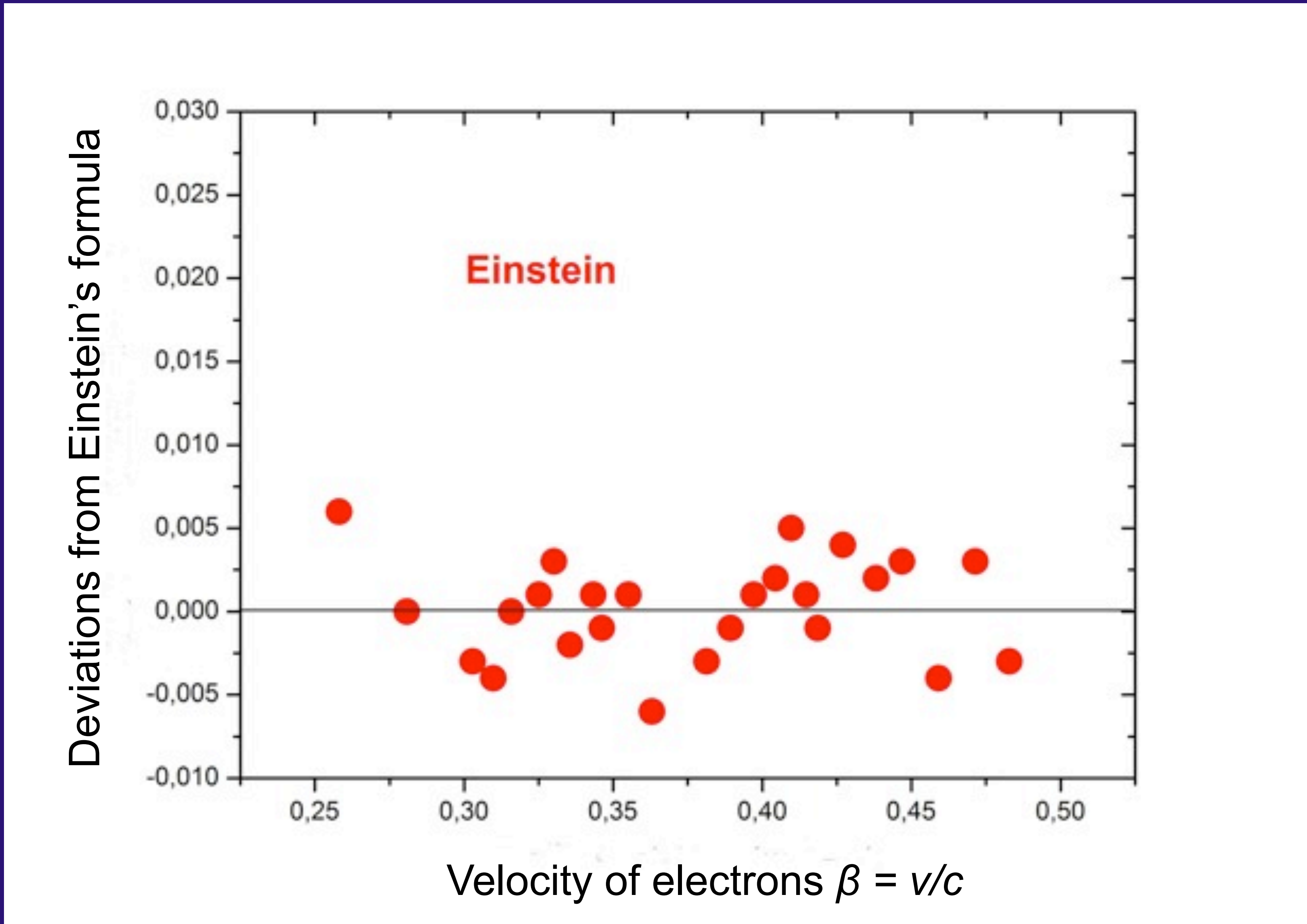
Neumann (1914) – **Lorentz-Einstein's formula better**

Guye & Lavanchy (1915) – **Lorentz-Einstein better**

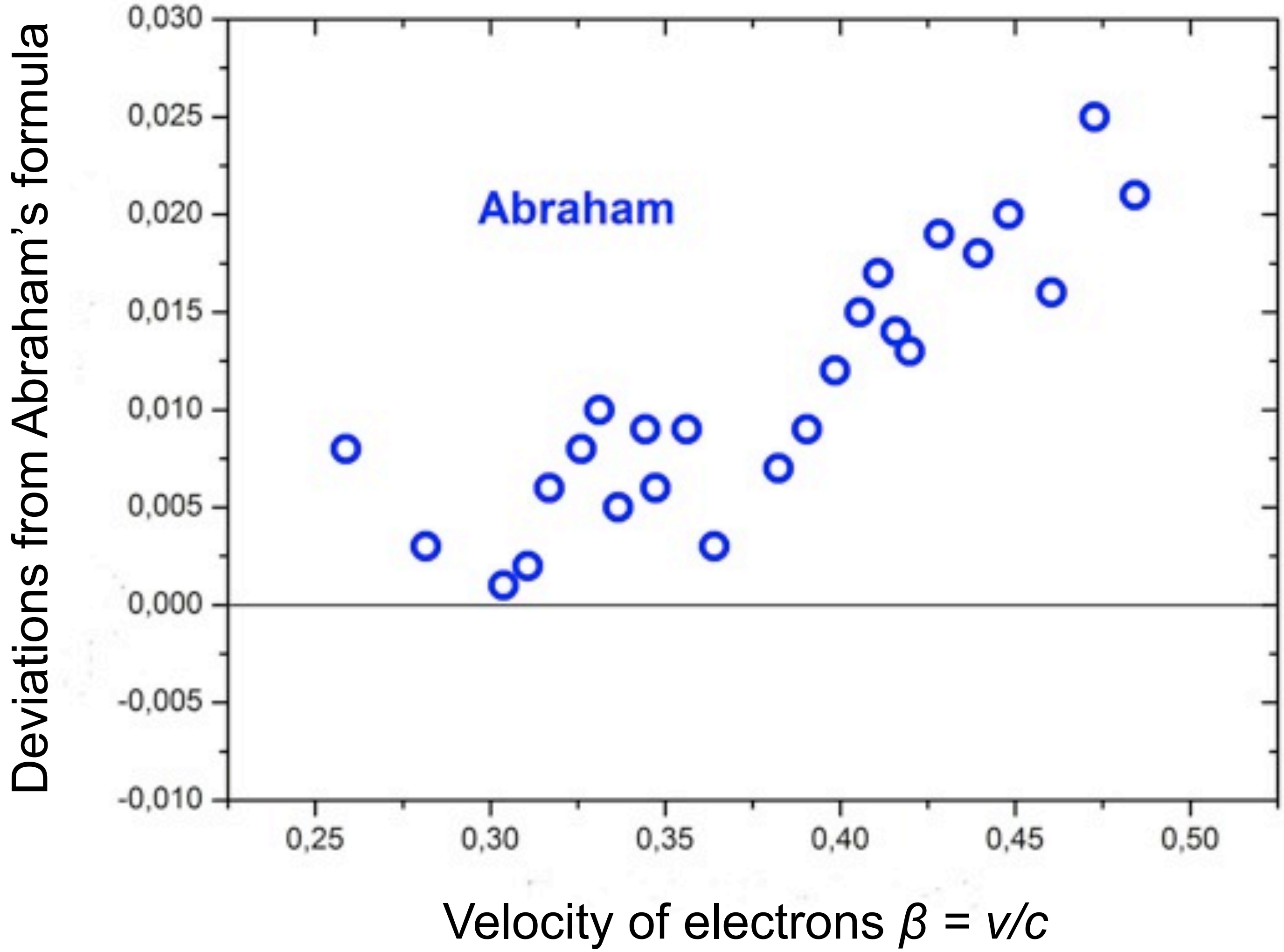


Neumann’s results of 1914

Guye & Lavanchy (1915)



Guye & Lavanchy (1915)



Einstein and Lorentz

Lorentz's paper of 1904 contained **eleven *ad hoc* hypotheses**

- restriction to small velocities, $v << c$
- postulation *a priori* of the [Lorentz] transformation equations
- assumption of a stationary ether
- stationary electron is spherical
- electron's charge is uniformly distributed
- all mass is electromagnetic
- the moving electron is contracted by $(1 – v^2/c^2)^{1/2}$
- forces between uncharged and charged particles have the same transformation properties as electrostatic forces in the electrostatic system
- all charges in atoms are in a certain number of 'electrons'
- each of these 'electrons' is acted on only by other 'electrons' of the same atom
- atoms in motion as a whole deform as electrons do

Einstein used only two postulates

- velocity of light in empty space *c* is the same in all inertial frames independently of the relative motion of an observer and a source
- principle of relativity: the laws of physics are identical in all inertial frames

and in addition:

- postulate of isotropy and homogeneity of space
- logical postulates concerning synchronization of clocks

  (if the clock at A runs synchronously with the clock at B, then the clock at B runs synchronously with the clock at A, etc.)

On the basis of these two postulates Einstein
derived [Lorentz] transformation equations
for the coordinates, time and fields,
and also
derived the formula for addition of velocities,
derived the formula for the Lorentz force
(which Lorentz only postulated in 1895)

“I introduced the conception of local time... but I never thought that this had anything to do with real time. This real time for me was still represented by the older classical notion of absolute time... There existed for me only one true time. I considered my time transformation only as a heuristic working hypothesis. So, the theory of relativity is really solely Einstein's work.”

Hendrik Lorentz (1927)

Einstein and Poincaré

Henri Poincaré – The principles of mathematical physics

”The principle of relativity, according to which the laws of physical phenomena should be the same, whether for an observer fixed, or for an observer carried along in a uniform movement of translation; so that we have not and could not have any means of discerning whether or not we are carried along in such a motion...

The most remarkable example of this new mathematical physics is, beyond contradiction, Maxwell’s electro-magnetic theory of light.

We know nothing of the ether, how its molecules are disposed, whether they attract or repel each other; but we know that this medium transmits at the same time the optical perturbations; we know that this transmission should be made conformably to the general principles of mechanics, and that suffices us for the establishment of the equations of the electromagnetic field...

Perhaps, likewise, we should construct a whole new mechanics, of which we only succeed in catching a glimpse, where inertia increasing with the velocity, the velocity of light would become an impassable limit. The ordinary mechanics, more simple, would remain a first approximation, since it would be true for velocities not too great, so that we should still find the old dynamics under the new.”

The 1904 St. Louis Congress of Arts and Science

”The deformable and compressible electron may be subject to a sort of constant external pressure proportional to the volume; it might be a possible cause of electron's contraction during its motion through the ether.”

H. Poincaré, *Sur la dynamique de l’electron* (June 1905)

Thus, there could be no doubt that Poincaré still upheld old concepts of the ether and deformable electron, despite his insistence on the principle of relativity.

Henri Poincaré

In 1909 Poincaré lectured in Goetingen on ”*La Mécanique Nouvelle*”
He based this new mechanics on three hypotheses:

1. The velocity of light in empty space is a limit which cannot be crossed by any body
2. The laws of physics are the same in all inertial frames
3. A body in translatory motion undergoes a deformation in the direction of motion.

”However strange this hypothesis may seem, we must admit that this third hypothesis is very well confirmed.”

Thus, four years after Einstein’s paper, Poincaré still did not understand that length contraction is a <u>consequence</u> of the two Einstein’s postulates

Einstein met Poincaré at the Solvay Council in 1911. Then he wrote to his friend Zangger:

”Poincaré was altogether simply negative about the relativity theory and, in spite of his acumen, showed little understanding for the situation”

Lorentz (b. 1853), Poincaré (b. 1854) and other eminent physicists realized the need of a new physics. They have discovered some important facts, but were convinced that ether must exist. That’s why their results had little connection with the revolutionary ideas of Einstein who belonged to a younger generation