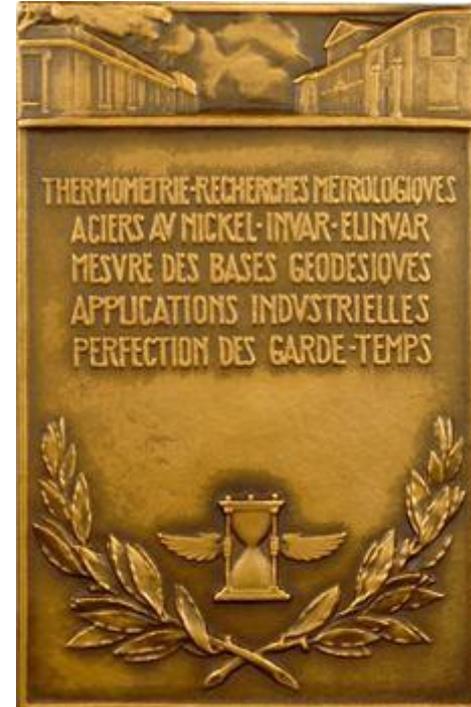
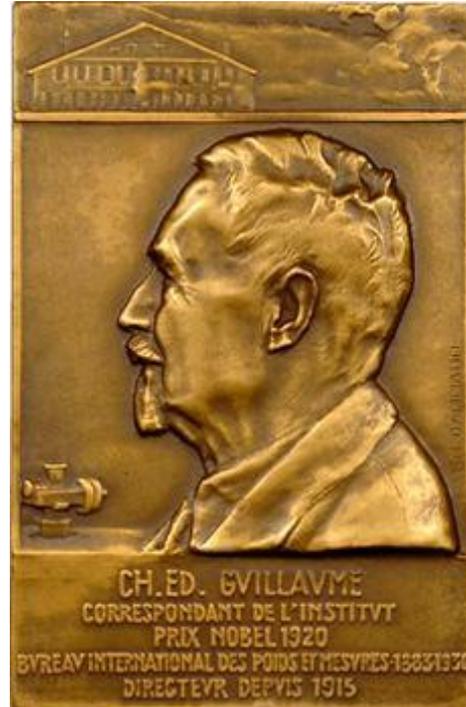


Charles-Édouard Guillaume and the International Bureau of Weights and Measures

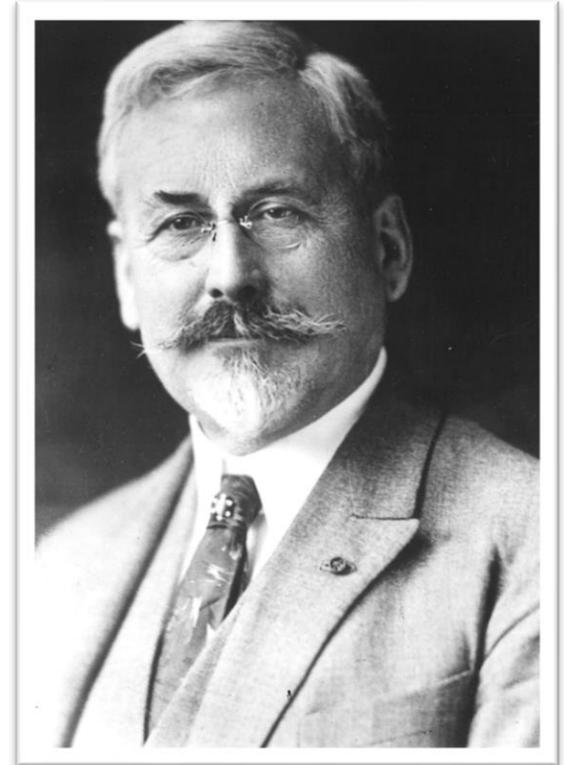
Céline Fellag Ariouet

Bureau
International des
Poids et
Mesures



Charles-Édouard Guillaume

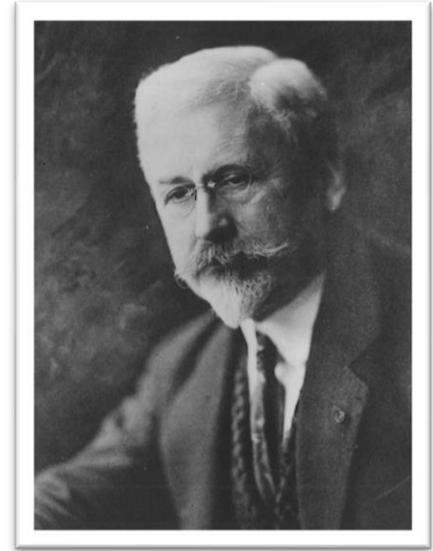
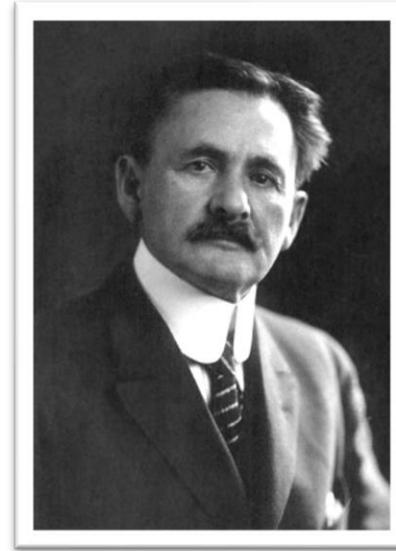
- A leading figure of the International Bureau of Weights and Measures.
- An exceptional scientific career that legitimizes a prosopographic study.
- Awarded the Nobel Prize in 1920, one year before Albert Einstein.
- A great notoriety during his lifetime but relatively little known today.
- A visionary man and a “multifaceted” figure.
- A man in the century with a reflection on the great debates and currents of thought.
- A figure at the heart of the national and international scientific community.
- His work goes far beyond the scope of his work at the International Bureau of Weights and Measures.



© BIPM

An iconic figure

- Among the members of the International Committee for Weights and Measures: 5 winners of the Nobel Prize in Physics.
- Charles-Édouard Guillaume is the only Director of the International Bureau to date to have been awarded the Nobel Prize.
- With Albert Michelson they are the only two Nobel Prize winners to have effectively worked at the BIPM.



From Fleurier to Sèvres

- Charles-Édouard Guillaume was born in Fleurier in the Swiss Haut Jura on 15 February 1861.
- He was from a family of watchmakers.
- 1876: Entered the Neuchâtel Gymnasium.
- 1878: Swiss Federal Institute of Technology in Zurich. He turned definitively towards physics. He was notably a pupil of Heinrich Friedrich Weber.
- In 1883, on the advice of Adolphe Hirsch, who was his teacher in Neuchâtel, he joined the Bureau International des Poids et Mesures.



© Jacques Boyer/Roger-Viollet

Engagement at the International Bureau

- Adolphe Hirsch recruited Guillaume in 1883.

Le SECRÉTAIRE expose que M. le D^r Benoît étant surchargé de travaux et devant l'être encore davantage lorsqu'il aura en outre le comparateur géodésique sous ses ordres, le Bureau du Comité a été d'accord avec M. le Directeur sur la convenance de lui adjoindre un second aide. Dans ce but, il propose d'attacher au Bureau un jeune physicien suisse, M. le D^r GUILLAUME, de Fleurier, élève de l'École Polytechnique et de l'Université de Zurich, et de lui accorder comme traitement celui des aides. M. Guillaume pourrait entrer en fonction dans le plus bref délai.

Cette proposition est adoptée à l'unanimité.



Adolphe Hirsch
1^{er} CIPM Secretary
(1875 - 1901)

Adolphe Hirsch

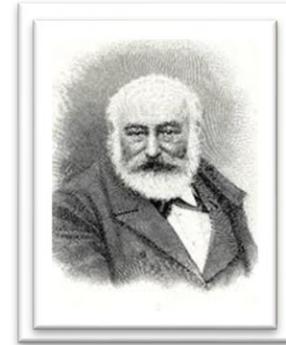
- Hirsch was very involved in the work of the Metre Commission.
- **The first meeting took place in 1870, just 150 years ago.** Adolphe Hirsch was involved in the first international initiative for geodesy, has been the main architect of the Metre Convention.
- A man of networks, he and his two main allies succeeded in imposing their project for a neutral, permanent, scientific and international organisation.
- In 1875, he became the first secretary of the International Committee for Weights and Measures.



Ibañez



Foerster



Hirsch

Adolphe Hirsch

- Hirsch saw in Guillaume the continuity of Switzerland's involvement in the institution.
- Hirsch facilitated the integration and career development of Charles-Édouard Guillaume at the BIPM and encouraged him to stay, as evidenced by this letter from the Secretary of the CIPM dated 10 May 1885.

Factuel
Comité international
des poids & mesures.
Monsieur C. Éd. Guillaume, à Brocail.
Monsieur, SX
Je s'empresse que le Bureau pourra proposer
au Comité, dans la session de Septembre, une nouvelle
amélioration de votre position, augmentant de
traitement et chambre au Bureau.
Pour que nous puissions le faire avec succès,
et sans inconvénient, j'espère de pouvoir donner
l'assurance que vous avez l'intention de rester au
moins encore une année au Bureau, et ensuite
il serait utile de pouvoir montrer sans les yeux
du Comité, de votre main en manuscrit, un travail
indépendant que vous auriez fait pour le Bureau
et Mémoires du Bureau et par lequel vous traverser
sans de nouvelles dans vos études de thermodynamique.
J'aimerais être éclairé par vous sur ces deux

grants, avant de commencer à préparer le
terrain confidemment au faveur de la pro-
position mentionnée.
Agréez, Monsieur le Directeur, l'assurance de
ma reconnaissance distinguée.
Dr. Ad. Hirsch



© BIPM

The BIPM

An international organisation established by a treaty in **1875**: the **Metre Convention**



CGPM – Conférence générale des poids et mesures

Plenary organ made up of representatives of Member States meeting every four to six years.



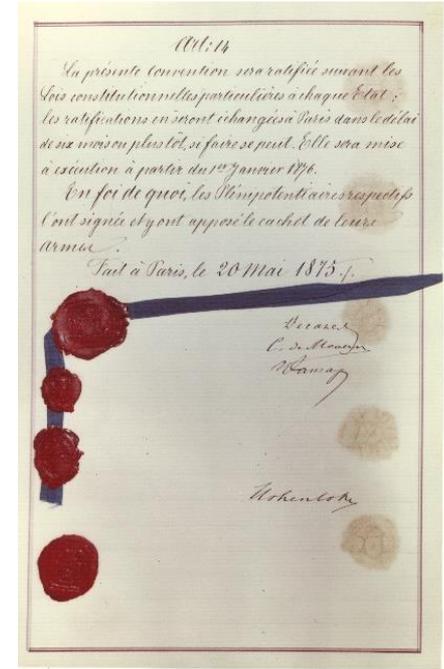
CIPM – Comité international des poids et mesures

*Supervising organ made up of fourteen members elected by the CGPM.
(currently eighteen)*



Secrétariat scientifique et technique à Sèvres

- *Coordination and international relations*
- *Technical coordination - laboratories*



Signed in Paris on 20 May 1875 by seventeen States, the Metre Convention is the founding act for the internationalisation of metrology.

The BIPM in 1883

When Charles-Édouard Guillaume joined the International Bureau of Weights and Measures in 1883, at the age of 22, the International Bureau had three missions:

Produce the new international prototypes of the metre and the kilogram = the two fundamental units of the Metric System.

Prepare and distribute the national prototypes for the States.

Ensure the adoption of the metric system at the international level.

The BIPM in 1883

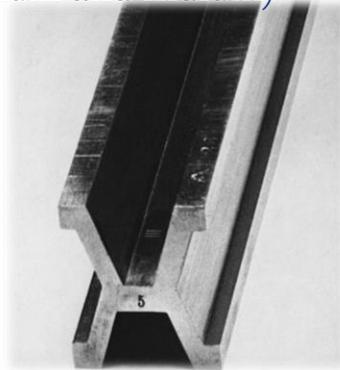


© Roger-Viollet

The International Bureau of Weights and Measures with, on the one hand, the Pavillon de Breteuil for housing and administration and, on the other hand, the Observatory to host the laboratories built in 1877, was operational from the end of 1878.

The new international prototypes

- At that time, the International Bureau of Weights and Measures (BIPM) was working on the manufacture of the future international prototypes of the metre and the kilogram, which were sanctioned in 1889 at the first General Conference on Weights and Measures.
- These prototypes were made from the old fundamental standards of the 18th century but with a better material (an alloy of platinum and iridium) and a better shape with regard to the metre.



*The old depository of metric prototypes.
The international standard of the metre (upper part).
The international prototype of the kilogram with its six
witnesses.*

The BIPM in 1883

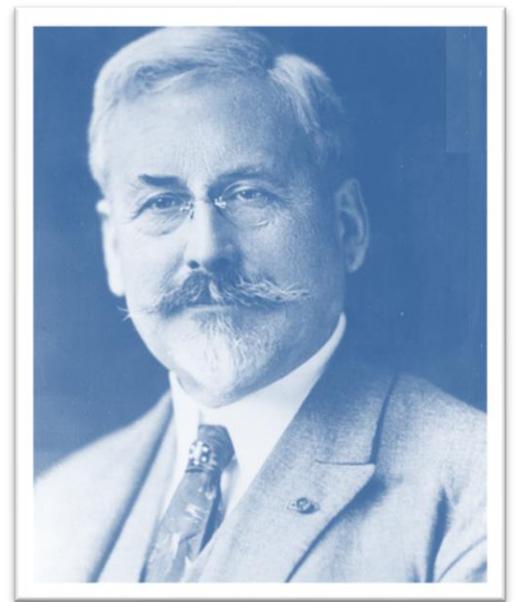
- In 1883, the International Bureau of Weights and Measures was a very young organisation that had been created eight years before. The metrological work had only started five or six years after the construction of the Observatoire and the installation of the first laboratories.
- In 1883, the Director was Ole-Jacob Broch since 1879.
- Guillaume had planned to stay one semester. He was in fact beginning a career of exceptional longevity: 53 years!



*Ole-Jacob Broch
BIPM Director
(1879 -1889)*

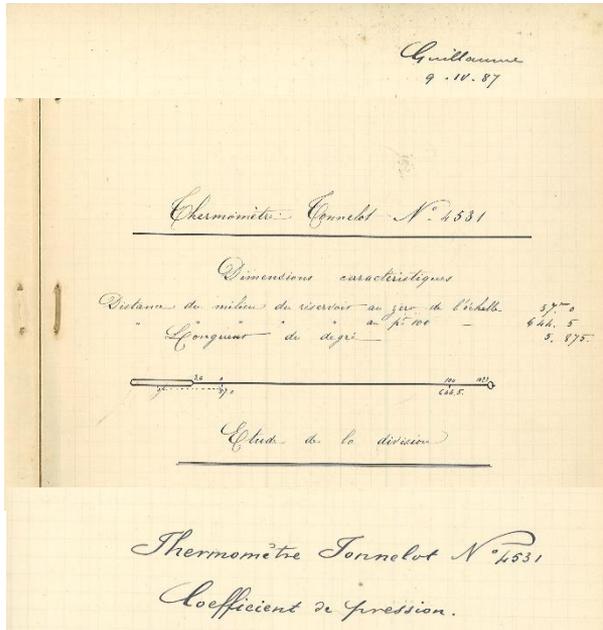
First work: thermometry

- In 1889: J.-René Benoît was appointed as Director of the International Bureau of Weights and Measures.
- With Charles-Édouard Guillaume, it was the beginning of a long collaboration.
- Charles-Édouard Guillaume became his deputy before being appointed as deputy director.



J.-René Benoît (1844-1922), director from 1878 to 1915, corresponding member of the Institute and of the Bureau des Longitudes. Benoît and Guillaume worked together for 32 years.

First work: thermometry

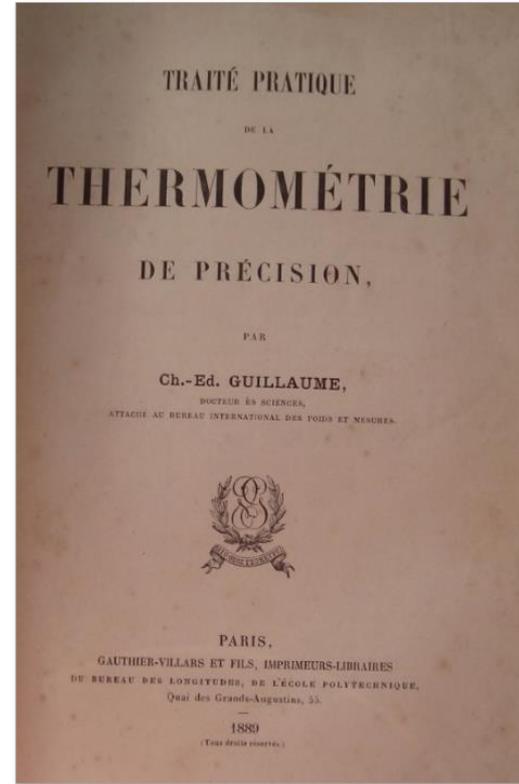


Calcul du Coefficient.

Pressions	H. Obs	Calc	-0-1	ou
738.7 p	2,0720	2,0720	+ 0,00000	0,0000000
738,3	200	220	+ 20	625
737,8	205	229	+ 36	1296
737,4	244	226	+ 11	121
736,9	285	222	+ 7	49
736,5	310	223	+ 22	1764
736,0	310	227	- 17	289
735,6	305	227	- 12	144
735,1	280	226	+ 4	16
734,7	220	226	- 6	36
734,2	220	225	- 15	225
733,8	220	224	+ 6	36
733,2	245	224	+ 11	441
732,8	260	224	+ 11	121
732,4	300	223	- 6,5	3529
731,4	310	221	- 2,5	229
731,1	310	221	- 11	144
730,8	300	221	- 22	484
730,5	310	221	- 11	121
730,2 p	2,0720	2,0721	- 0,0001	0,0000001
14 693,5 p		1,8810	+ 0,192	0,0001161
p		2,000 125 97	2,0,000 000 20	- 0,019 2
p		2,000 38		
p		2,000 120 4		



A Tonnelot thermometer was supplied to control the thermal expansion of Pt-Ir.



Traité de thermométrie (1889)

1896: invar

- 1896: Benoît noticed an anomaly on an alloy.
- The alloy studied was from Imphy. It was not a coincidence!
- Guillaume decided to launch an in-depth research on this anomaly.
- Guillaume obtained the agreement of J.-R. Benoît.
.... But he had to find a way to obtain alloys.

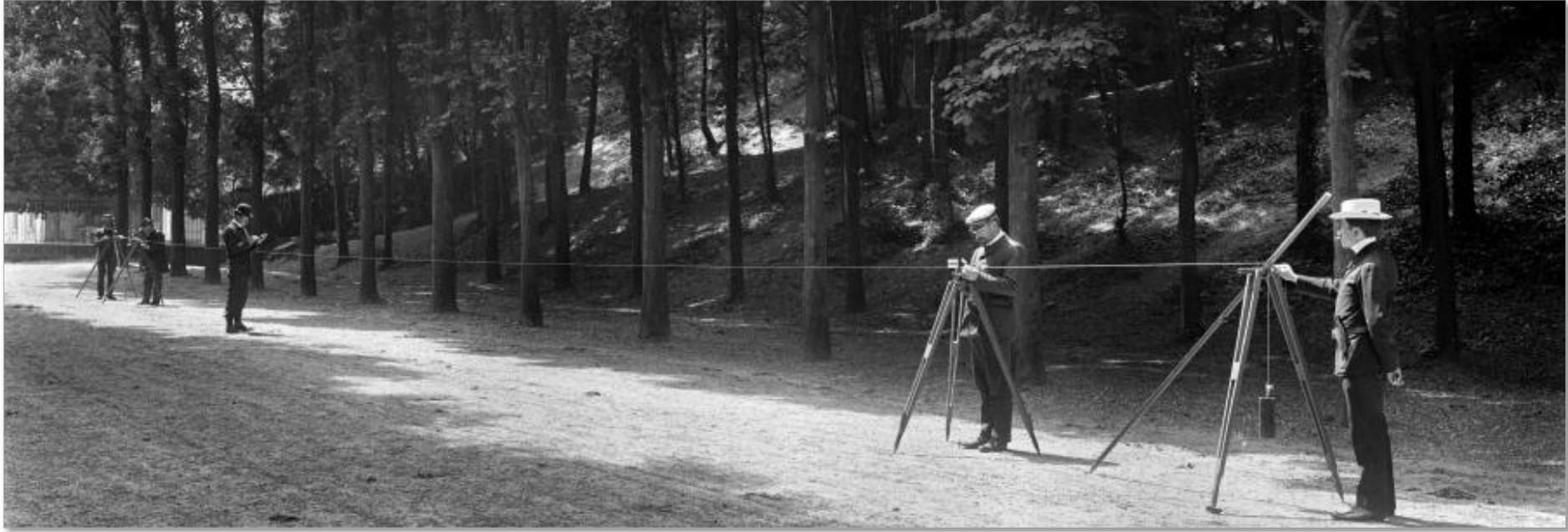
Invar: a step forward for the BIPM

- The discovery of invar was of interest to geodesians.
- The study of the rules was one of the missions of the International Bureau.
- In just a few years, the BIPM had become the indispensable centre for the calibration of the rules at the departure and return of each expedition.
- 1899: invar was used for the first time during measurements of the Meridian Arc of Spitzberg.
- With the invar and Jäderin's invention, Guillaume revolutionized practices survey measurement.



© Jacques Boyer/Roger-Viollet

A revolution for survey measurement



© Jacques Boyer/Roger-Viollet

A revolution for survey measurement



© Jacques Boyer/Roger-Viollet

Measures in the courtyard of the International Bureau of Weights and Measures.



© BIPM

Charles-Édouard Guillaume measuring in the 24 m long geodetic base installed in the basement of the Observatory.

1906: the alignment of the Simplon Tunnel

- A campaign in the field led by C.-É. Guillaume
- A technological and geodesic feat.
- A multidisciplinary cooperation.



© BIPM



© BIPM

- 5 days, 59 hours one way.
- Exceptional results with a difference of only 3 mm between outward and return measurements.

1906 : Le Simplon : un tournant pour la géodésie

- A resounding echo.
- Many publications.
- A turning point for the whole of geodesy.

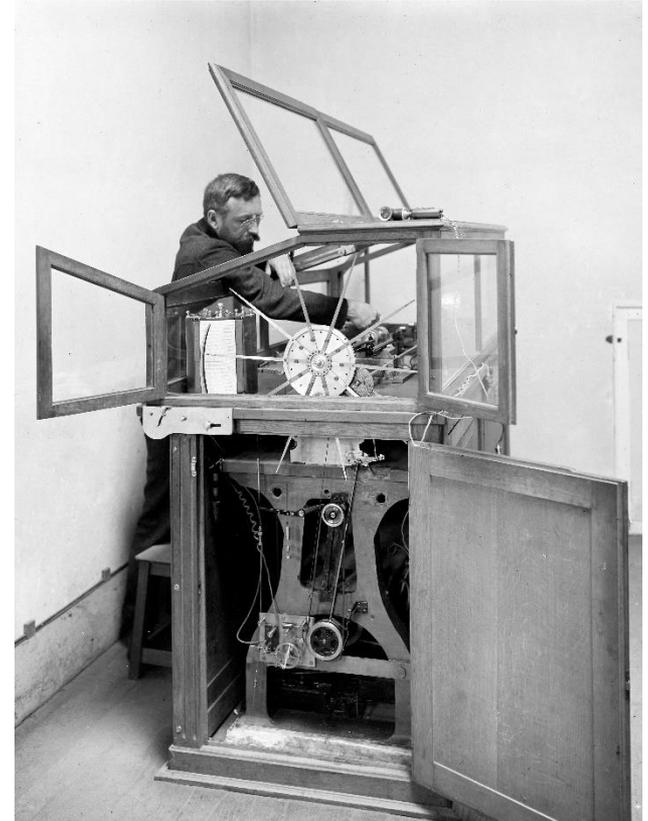


© BIPM

« The comparison of its length with the angular distance of the two observatories on the celestial sphere gives at once the sum of the deviations, i.e. the abnormal curvature of the geoid in this region of the globe. For all these reasons, the recent measurement of the base of the Simplon constitutes a major event for the whole of Geodesy (...) The Simplon massif has been one of the best explored places in terms of its geodetic features in just a few years. As the relief of the ground shows very strong anomalies, the exceptional interest of all these studies is understandable. »

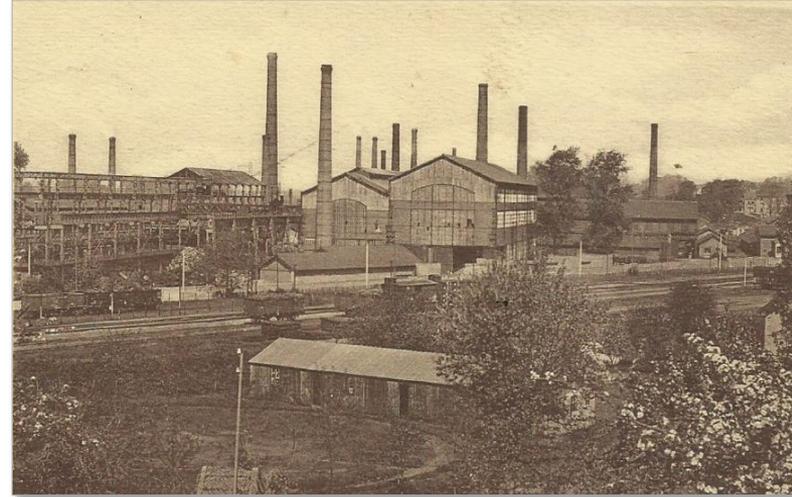
Start of the collaboration with Imphy

- **1895:** Colonel Gaston-Louis Hartmann (1851-1922), Director of the Artillery Workshops in Puteaux and member of the National Bureau of Weights and Measures, developed an automatic comparator acquired by the International Bureau.
- Hartmann worked on iron and nickel alloys, also with the idea of finding a stainless, stable and reasonably priced metal or alloy.
- Colonel Hartmann was very involved in the standardisation of industrial measurements: it was he who put Louis Dumas (1850-1928), head of the metallurgical department of the Imphy Steelworks, in contact with the management of the International Bureau.



A new age for Imphy

- After the war of 1870, Imphy went through a deep crisis (1865-1875).
- 1871: loss of Alsace and part of the mining territories of Lorraine.
- Economic crisis of the 1880-1890s "Great Depression".
- First World War: strategic position.
- The invar: a new age for Imphy.



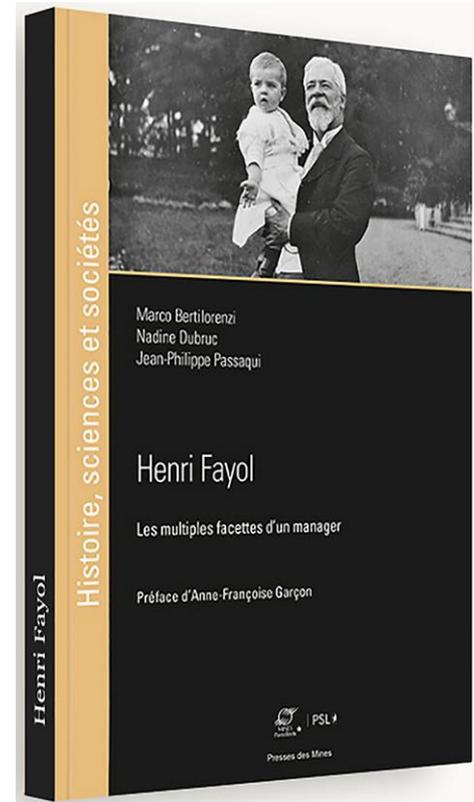
Ci-contre : photographie du buste érigé à Imphy, le 26 juin 1954, à la mémoire de Charles-Edouard Guillaume et en témoignage de son rôle déterminant dans l'orientation scientifique des Acières d'Imphy.
Sur le socle du buste, on relève les deux inscriptions :
Face antérieure : « Charles-Edouard Guillaume, 1861-1938, créateur de l'Invar (1896) et initiateur de la métallurgie de précision en collaboration avec les Acières d'Imphy. Prix Nobel 1920 ».
Face postérieure : « Monument inauguré le 26 juin 1954 par Pierre Chevenard, de l'Institut, qui a étendu l'œuvre de Charles-Edouard Guillaume et contribué au progrès des alliages sidérurgiques spéciaux. »

Start of the collaboration with Imphy

- First tests for Guillaume's research were carried out when Dumas, was head of the Metallurgy Department.
- In 1897, Guillaume, with 17 alloys, found the minimum dilatation but did not stop there: *"after dilatation, I resolved to study stability, then the action of additions, then that of treatments, then elasticity."*

Henri Fayol

- Like Guillaume, Fayol (1869-1925) was a "multifaceted" character. Former student of the Ecole des Mines de Saint-Etienne. He joined Commentry-Fourchambeau and Decazeville at the age of 19.
- Managing Director from 1888 to 1918.
- In 1916, he published “*Administration industrielle et Générale*”, a landmark work. Fayol's theories are regularly revisited and analysed.



Pierre Chevenard

- Pierre Chevenard was hired in 1909, having just graduated from the École des Mines de Saint-Étienne. This was an opportunity for Chevenard to devote himself to metallographic work. He succeeded to Louis Dumas in 1911.
- In 1912, Fayol asked him, in accordance with Guillaume's recommendations, to *“scrutinise special steel alloys in order to discover and exploit their exceptional properties.”*
- Chevenard developed very successfully many devices to measure these properties: Chevenard's laboratory became a precision instrument laboratory
- He taught at the Ecole des Mines de Saint-Etienne from 1919 to 1935 and at the Ecole des Mines de Paris from 1942.
- Numerous scientific publications. Member of the French Academy of Sciences in 1946.



A new way to think collaboration between science and industry

- Henri Fayol, Charles-Édouard Guillaume and Pierre Chevenard made up Imphy's "**État Major**".
- Pioneers of conceptual research and of a metallurgy that would no longer be quantitative but of precision.
- They developed a new way of thinking about the relationship between science and industry. An essential element of the "Fayolian turn".
- An intensive innovation policy based on a research laboratory headed by Pierre Chevenard and the development of precision instruments.
- A systematic study of the properties of alloys was carried out. An industrial development based on the physicochemical laws of alloys and no longer on maps linking the composition of alloys to their properties.



Henri Fayol
(1841-1925)



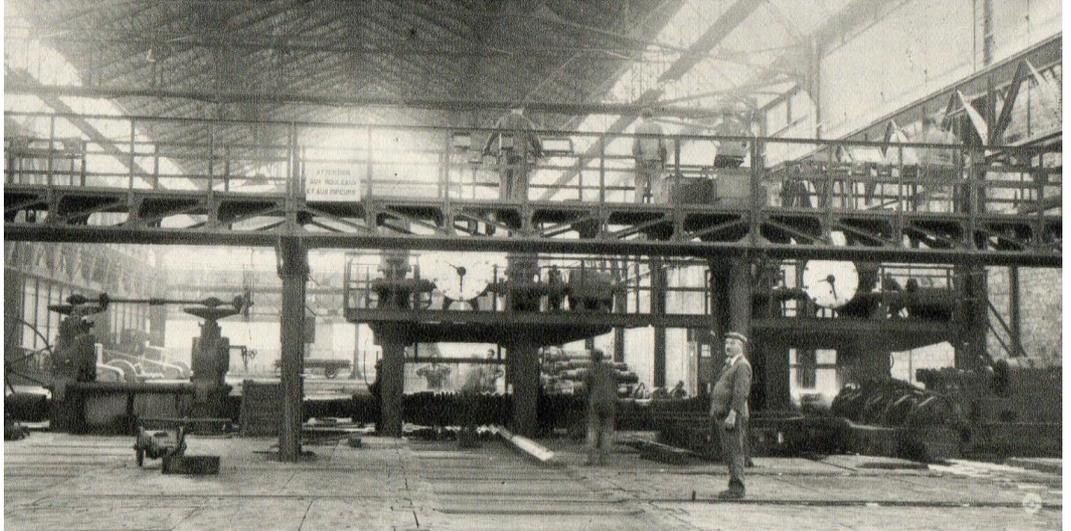
Pierre Chevenard
(1888-1960)



Charles-Edouard Guillaume
(1861-1938)

A new way to think collaboration between science and industry

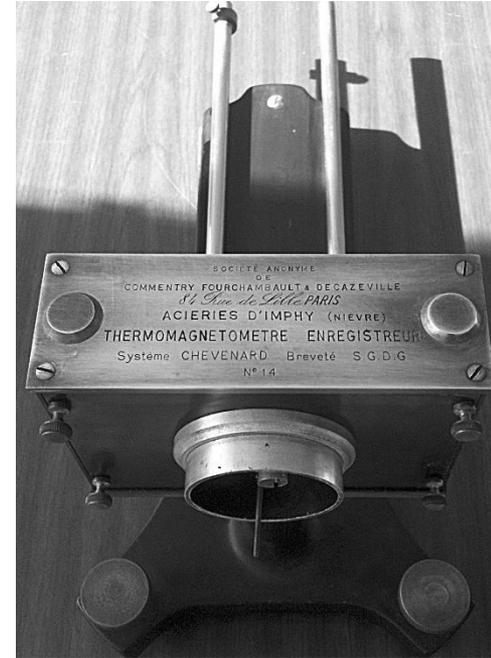
- Reorientation of production at Imphy towards special steel alloys.
- 1907 invar is patented.
- 1911-1914 : construction of the design laboratory.



***Chevenard :** "One consequence of the work [with Guillaume] was to orient Imphy towards precision metallurgy, to familiarise the staff with meticulous techniques, to create a scientific atmosphere in the factory. "*

A new way to think collaboration between science and industry

- Fayol, Chevenard and Guillaume were pioneers in the development of precision metallurgy based on a research laboratory and precision measuring instruments.
- Chevenard's laboratory was above all a laboratory of precision instruments; it developed several devices and instruments: the recording differential dilatometer, completed in 1916. Several thousand units were subsequently improved and sold throughout the world: study of metals, rocks, control of the manufacture of ceramic and refractory products, and led to the discovery of glass tempering phenomena.
- The torsion oscillometer for the study of thermoelasticity, with which Pierre Chevenard with Charles-Edouard Guillaume developed metals such as elinvar.
- The thermomagnetometer which automatically drew the magnetization variation curves as a function of temperature.



A new way to think collaboration between science and industry

- At Imphy, under the impulse of Guillaume, two axes of development: the systematic study of the properties of alloys and especially the capacity to transform alloys by additions.
- As anomalies only exist in a limited field, chromium or manganese is used to "dilute" certain anomalies.
- As Chevenard outlined *“the physico-chemical role of additions makes it possible to predict at least qualitatively the role of additives, to calculate the quantities of additions (...) the broad outlines of the phenomenon having been drawn in advance, it will suffice to specify a few experimental points, in the field of interest or a particular point.”*

Multiple applications

- A considerable list of alloys with multiple applications and, above all, an impressive number of properties studied in Chevenard's laboratory: from the negligible dilatibility of invar to the weldability to glass of platinite to alloys with high resistivity and low thermal coefficients, anti-corrosion alloys, rigid alloys at high temperatures, non-brittle alloys at very low temperatures, etc....
(Pascal Le Masson and Benoît Weill *"Science, industry and the exploration of the unknown: logic and governance of design research"*, 2016).
- New alloys were not generated one by one but developed based on new performance measuring devices.
- Guillaume signed with Imphy several agreements that defined the framework of his collaboration with the company Commentry Fourchambault and Decazeville.

A long collaboration with the industry

- 600 alloys were supplied to BIPM for the work of Charles-Édouard Guillaume over a period of 25 years.
- By collaborating with Imphy, Charles-Edouard Guillaume has theorised and implemented conceptual and innovative research.
- A collaboration with industry that also had an impact for Guillaume on the way he thought about his research work :

« When one preaches an increasingly intimate union of science and industry, one can only say one thing: that industry has much to gain from drawing inspiration from scientific methods. But the counterpart is omitted: it is forgotten to say that scientists could very usefully draw inspiration from industrial methods. »

A long collaboration with industry

- Charles-Édouard Guillaume multiplied his incursions into various scientific and industrial circles.
- Imphy is not his only collaboration with an industrialist.
- In 1905, he researched low temperatures and contacted Air Liquide, of which he was a member of the Board of Directors.
- The industrial application of Guillaume's discoveries for watchmaking and chronometry was entrusted to the “Fabriques des Spiraux Réunies” company.
- **A significant “marge de manœuvre” for the director of an international organisation!**

« Hors les murs »

- It is a marker of "Guillaume" governance: openness to different circles.
- French Physical Society, French Astronomical Society, Bureau des Longitudes, many Academies of Sciences: an important opening in a context of nationalist tensions at the time of the war for an organisation with a German President.
- He collaborated in popular science journals: numerous articles published in *La Nature* on a wide variety of subjects: from geodesy to radioactivity and space temperature.
- An impressive list of publications : books, articles, conference proceedings.
- Carried out measurements with invar wires at the Eiffel Tower.
- Had a significant “marge de manoeuvre” for the director of an international organisation.

« Hors les murs »

- Camille Flammarion, Pierre and Marie Curie, Paul Langevin, Lucien Poincaré, Henri Poincaré... Charles-Édouard Guillaume frequented the greatest scientists of his time. His son André-Charles Guillaume declared:

"I knew two thirds of those who formed the elite of the physical sciences in my father's house. »

- Guillaume met Albert Einstein for the first time at the Eiffel Tower's radiotelegraphy station: Einstein wrote him the letter below in April 1913 :

Paris, 1. April 1913.

Hoch geehrter Herr Guillaume!

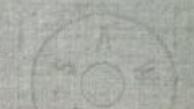
Es drängt mich dazu, Ihnen von Herzen zu danken für die grossen Aufmerksamkeiten, die Sie mir und meiner Frau erwiesen haben. Ganz besonders erquickte mich der Besuch der Funktelegraphischen Station am Eiffelturm.

Paris hat einen unansprechlichen, schon ausserordentlichem Eindruck auf mich gemacht. Die Fülle von Geschmacks im Grossen und im Kleinen, der nicht bloss ästhetische Geist der Stadt, die ich mich selber kennen gelernt habe! Jede ist da er selbst misst die Reproduktion der von ihm ausgefüllten Stellung (sonst studiere auch in der Schweiz nicht)

Von den ausserordentlichem Komplimenten, die Sie mir an die offiziellen Sitzungen gemacht haben, danke ich, dass Sie zur Anwesenheit einer solchen Sitzung gehen. Eine Blumen zu mir eine vornehmer Mensch! Sie waren der Weltkommission nicht anwesend gefährlich, so wenig als stark geschwächt. Namen der Teilnehmer der sie begleitete. Jede immer voraus es mich, dass mir einige Ihrer guten Briefe zugegangen sind, weil ich darauf sehr gespannt bin. Überhaupt geht es unheimlich in Gesellschaft einiger geistlicher Freunde, wie bei einer Aufstiege in Gesellschaft von interessanter Tätigkeit. Inzwischen geht man der Teilnahme aus, oder man muss sich getrennt, schreiben und geben lassen und ist so die andere.

Mit herzlichsten besten Dankesgrüssen Sie.

The young engineer
A. Einstein.



« I will always regret forgetting some of your good stories, as they had caught my attention. In fact, when you are in the company of a few cultured French people, you have the impression that you are following a group of experienced mountain people; either you lose your breath, or you drag yourself miserably until you are towed by the others. »

The international radium standard

- In 1912, Guillaume agreed to keep the first international radium standard at the BIPM.
- He actively participated in the drafting of the regulations relating to the conservation of the standard.
- An audacious initiative and an unofficial activity.



Governance

- Charles-Édouard Guillaume took over as head of the organisation in 1915, one year after the start of the First World War. This was a very complicated period, particularly in financial terms, as the war prevented the payment of contributions of many Member States.
- The International Committee could not meet for 7 years.
- During this period, it continued its laboratory work, set up the basis for the extension of the activities of the International Bureau and continued its research on iron and nickel alloys.
- In 1916, violent attacks took place in the press because of the nationality of the President of the International Committee and the mistrust of the International Bureau in the midst of a period of nationalist feelings. These pamphlets were taken up again in the Senate and called into question the need to maintain an International Bureau in France. Criticisms were taken very seriously and Guillaume responded in a long article published in a French newspaper.
- These events were to have a strong impact, particularly on the need to promote strict neutrality of the organisation at the international level.

Looking ahead

- In 1920, Charles-Édouard Guillaume refused to affiliate the International Bureau of Weights and Measures to the League of Nations. Pérard, who succeeded to him in 1936 but who had started to work at the International Bureau in 1905, pursued this strategy:

« My predecessor did not want to join the League of Nations; events proved him right. I did not want us to join UNESCO. »

- Its strategy was to ensure maximum representation of the organisation within the various international and national scientific unions in order to make its voice heard and at the same time to preserve the independence of the organisation.
- This decision was followed by its successor after the Second World War: the BIPM will not become an organisation under the umbrella of the UN or UNESCO.

Electrical units

- Charles-Édouard Guillaume also initiated the extension of the International Bureau's activities to the fields of electricity.
- This extension was the decisive step towards the constitution of the International System of Units (SI).
- It was also under his mandate that the first Consultative Committee was created: the Consultative Committee for Electricity (CCE) in 1927.

1929 : construction of the « Nouvel Observatoire »

- In 1929, a new building was constructed as an extension of the first Observatory.
- Guillaume submitted a request to the Rockefeller Foundation and obtained the funding.



Achievements

- In 1927, in the historical introduction to a book intended to commemorate the fiftieth anniversary of the BIPM, Daniel Isaachsen, Secretary of the CIPM, summed up the achievements of the first fifty years as follows:

“During the years that followed the first Conference, the International Bureau gave amazing evidence of its vitality. It is at that time that, in addition to the issues agreed in its programme, it undertook the precise determination of fundamental wavelengths of light. This work enabled the BIPM shortly after to apply interferometric techniques to the measurement of cubes made of crown glass or quartz and this led unexpectedly to a method for determining the volume of a kilogram of water. Much later, the BIPM applying the same method was able to supplement the international prototype [of the metre] with secondary quartz standards, thereby contributing to the secure conservation of the metric unit. At the same time, the BIPM started to study industrial end-gauge standards, which gave a new impetus to its activity. Finally, it undertook research on alloys and, after some time, these studies led to results that would revolutionize geodesy. All this work was an extension of the programme initially planned. Moreover, the great interest in these activities could not be ignored. Il s’agit de la première Conférence générale des poids et mesures (1889). One of the results of these recherches was the discovery of invar for which Charles-Édouard Guillaume was awarded the Nobel Prize in Physics in 1920.”*

* First meeting of the General Conference on Weights and Measures (CGPM) in 1889.

1920: the Nobel Prize

- In 1920, he was awarded the Nobel Prize.
- This prize rewarded twenty-five years of research dedicated to metrological precision research and physics for practical applications oriented towards society.
- The Nobel Prize was also an opportunity for the International Bureau to acquire a new notoriety..



1920



- At the right of Einstein:
Paul Langevin, Charles Fabry (1867-1945), Charles-Édouard Guillaume, then two unknown persons, Paul Appell (1855-1930). On Einstein's left,
Louis Lapicque (1866-1952), Marie Curie. At the bottom of the photo Émile Borel (1871-1956, son-in-law of Appell), and Jean Becquerel (1878-1953, son of Henri Becquerel).



© Jacques Boyer/Roger-Viollet

“As far back as I can remember, I see my father at work; a work every moment of the day, every day of the year. When he was travelling, he was always bringing a lot of writing material with him and every day he devoted a few hours to writing (...) Even its distractions were scientific in nature.”

André-Charles-Édouard Guillaume

“A great metrologist of the French language, Charles Baudelaire, said ‘Inspiration means working all day long’. Filled with this profound sense, metrologists accept the difficult times that sometime come in the course of performing an accurate measurement.”

Charles-Édouard Guillaume, 1927

A handwritten signature in dark ink, which appears to read 'Ch. Guillaume'.

Thanks!