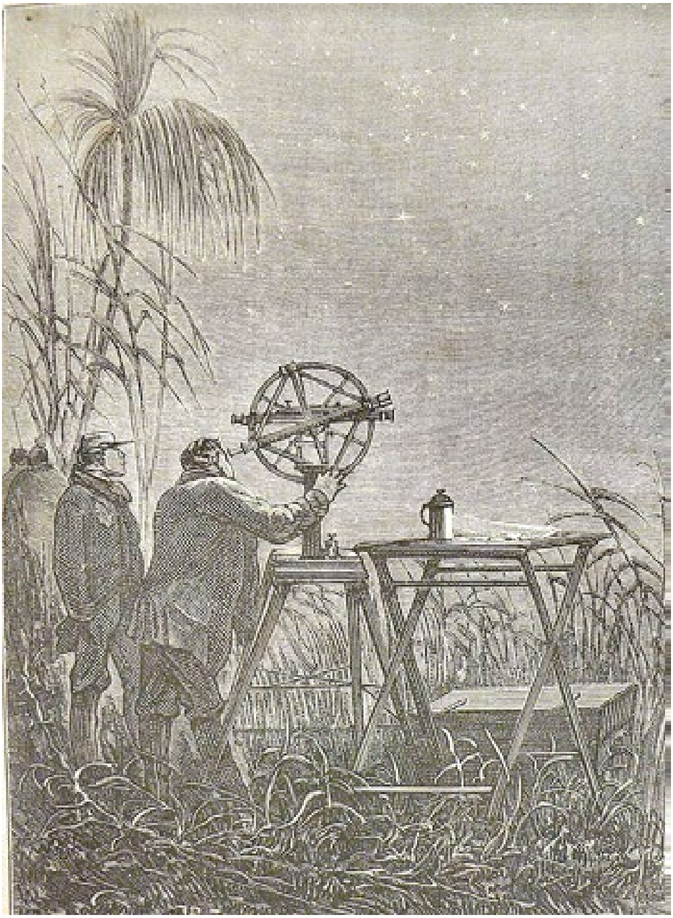
MUSÉE
D'HISTOIRE
DES SCIENCES
GENÈVE

History of science museum's booklets n° 9

From foot to metre, from marc to kilo



Une institution
Ville de Genève

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VILLE DE GENÈVE

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Cover: Repeating circle measurement
Jules Verne, Aventures de trois Russes et de trois Anglais en Afrique australe, Paris, 1872
History of science museum Library

The history of weights and measures illustrated by objects in the collections of the Musée d'histoire des sciences

This booklet gives a brief account of a key chapter in the development of metrology : the transformation from traditional units of length and weight to the metric system. It presents some instruments made in Geneva which played an important role in metrology : rulers, dividing engines, measuring machines, etc.

Laboratory precision scales
MHS 718
Steel, cast iron, brass, Deleuil, Paris, 19th century

The foot

One of the oldest units of measurement

Before the introduction of the metre during the French Revolution, units of length were based on parts of the human body. One of the oldest is the Nippur cubit 51.85 cm long used in Mesopotamia in the 3rd millennium BC. Later, Egyptian surveyors divided the cubit into 28 equal parts or digits. Sixteen digits yielded a new unit, the foot, 29.633 cm in length which was later adopted by the Romans.

During the Middle Ages, a new foot measurement appeared derived more or less directly from the Romans. For practical reasons, it was divided into 12 equal parts or inches. The foot or its multiples such as the yard or the toise became the preferred standard for the measurement of length over most of Europe. It did not disappear until the 19th century following the gradual introduction of the metric system.

Only the Anglo-Saxon countries still legally maintain measures in feet, divided into 12 inches. This is the case, for example, in the information technology and aeronautical industries in Britain.

Vaud foot
MHS 434
Wood, brass, 19th century

Pied de roi (King foot)
MHS 978
Ivory, 19th century

Several Swiss feet

Co-existence of different units of length

Switzerland inherited three units of length from the Romans: the step, the cubit and the foot. The latter became the most widespread.

During the Middle Ages and under the Ancien Régime three different foot lengths were used according to region: the Nuremberg (30.38 cm) in the east, the Berne (29.33 cm) in the Bernese areas and the foot of the French king (32.48 cm) in Geneva. Still more feet of different lengths were used by carpenters, stone cutters and surveyors.

In 1801, the Helvetic Republic was given a copy of the revolutionary standard metre bar. A law was passed ordering the introduction of a standardised system of weights and measures based on the palme, the unit of reference equal to one-tenth of the French metre. The law was never applied because control of weights and measures was the responsibility of the cantons …

In 1835, 12 cantons signed an agreement to try and unify their systems of measurement. They attempted to adapt the metric system to the old units, with mixed results. For example, the Federal foot measured 30 cms and was divided into 10 inches of 3 cm each. Six feet equalled a toise (1.8 m) and 10 feet a perch. Weights and measures in Switzerland were not finally unified until 1877 when the metric system was imposed on the entire country.

SUISSE. (République helvétique).

NOMS des MESURES ÉTRANGÈRES.	VALEUR EN							
	Pieds de Paris, de 12 pces. ou 144 lig.	Pouces de Paris, de 12 lig.	Lignes de Paris.	Conversion de la mesure en lignes de Paris.	Mètres de 443 lig. ,296 mill.	Décimètr. de 44 lig. ,3296 dix milièmes.	Centimèt. de 4 lignes ,43296 cent mill.	Fraction de centimètre.
Le pied vaut.............	″	11	1	133	″	3	0	00253

N.° 1. Pour convertir les pieds de Suisse en pieds de Paris, multipliez les pieds de Suisse à convertir par le nombre 0,923611, et retranchez 6 chiffres sur la droite. Le produit sera la réponse.

N.° 2. Pour convertir les pieds de Paris en pieds de Suisse, multipliez les pieds de Paris par 1,0827067, et retranchez 7 chiffres sur la droite.

N.° 3. Pour convertir les pieds de Suisse en mètres, multipliez les pieds de Suisse par 0,3000253, et retranchez 7 chiffres sur la droite.

N.° 4. Pour convertir les mètres en pieds de Suisse, multipliez les mètres par 3,333334, et retranchez 6 chiffres sur la droite.

Conversion table for the Swiss foot to the metre

Palaiseau, Métrologie universelle ancienne et moderne, Bordeaux, 1816

History of science museum Library

Revolutionary metre (1)

A measurement free of reference to humans

Faced by the plethora of measurements under the Ancien Régime, the French revolutionaries demanded a new universal unit free of links to the size of parts of the human body. In 1791 three systems were proposed: the length a pendulum swings in one second at latitude 45°; the length of a quadrant of the equator, or the length of one quarter of a terrestrial meridian. The third was finally adopted. The new metre (from the Greek word metros, the measure) was defined as one ten-millionth of a quarter of the earth's meridian passing through Paris.

In 1792, the French National Assembly commissioned two scientists, Pierre Méchain (1744-1804) and Jean-Baptiste Delambre (1749-1822) to determine the length of the metre. They chose to measure the meridian circle between Dunkirk and Barcelona passing through Paris.

After seven exhausting years interrupted by war, accidents, the destruction of their instruments and arrests, the two scientists achieved their mission. From 1799 the Mètre des archives (a platinum rectangular metre bar), became the standard for the new revolutionary unit of length. Unlike the foot of the Ancien régime, the metric system is based on decimal divisions.

CONVERSIONS

Des Mesures longues anciennes en MÈTRES.

PIEDS.	Mètres. Millimèt.
1,000 pieds de roi, *tous les départemens*,	324'839
1,000 pieds de Bonneville, *Léman*	340,110
1,000 pieds anciens de Bourgogne, *Jura*,	331'200
1,000 pieds de chambre, *Léman et Mont-Blanc*,	342'110
1,000 pieds dits le comte, *Jura*,	358'
1,000 pieds liprans, *Mont-Blanc et Piémont*,	514'200
1,000 pieds de Lyon dits de ville, *Rhône*,	342'400
1,000 pieds de Ville-Franche, *Rhône*,	324'839

PIEDS ÉTRANGERS.	
1,000 pieds d'Amsterdam,	283'
1,000 pieds anglais,	304'700
1,000 pieds de Berlin,	309'727
1,000 pieds de Berne, *Helvétie*,	293'257
1,000 pieds chinois pour l'arpentage,	320'
1,000 pieds du Rhin,	313'900
1,000 pieds de Russie,	354'100
1,000 pieds de Suède,	297'100
1,000 pieds de Vienne, *Autriche*,	316'
1,000 pieds de Zurich, *Helvétie*,	300'025

D 4

Conversion table for feet into meters
Téron, Instruction sur le système de mesures et poids uniformes
pour toute la République française, Genève, 1802
History of science museum Library

Revolutionary metre (2)

A new unit based on nature

In order to measure the length of the arc between Dunkirk and Barcelona, Méchain and Delambre used triangulation. This technique, still in use today, covers the arc to be measured with a series of triangles with a baseline of about 10 km in length. Each of the points of the triangles is linked to a prominent feature such as a church steeple or the top of a mountain, etc.).

The two scientists first produced a basic reference measure on the ground of about 10 km, corresponding to the length of one side of the triangles. With a repeating circle, a very accurate measuring instrument which repeated each measurement several times in order to minimise errors, they then determined all the angles of the triangles point after point, triangle after triangle. They also precisely calculated the latitude of the two towns at each end of the meridional arc in order to determine its amplitude. Applying trigonometry, they were able to calculate the length of each side of all the triangles as well as their projection on the meridian arc and thus its true length. They concluded that a quarter of the terrestrial meridian equals 5,130,740 toises and that the metre therefore equals 0.5130740 toises.

Repeating circle
MHS 2644
Steel, brass, Bellet, Paris, 19th century

Measurement of weights

A proliferation of units

Before the French Revolution the use of weights was anarchic. They often varied from one country to another or even between different towns.

The situation in Switzerland, where local and international systems co-existed, was as chaotic as elsewhere. In Geneva, for example, the marc, the standard unit for valuing money, weighed 275 grammes while the Parisian marc, the international standard, weighed 244.753 g. The livre, the basic unit for the retail trade, was no less confusing : in the markets of Geneva, the livre weighed 550.7 g while the livre in Paris, used for spices and other imported goods, weighed only 489.5 g. To these two different livres was added the livre poids de soie (458.906 g) used for the wholesale silk trade. The three livres were divided into 18 (Geneva livre), 16 (Parisian livre) and 15 (livre de soie) ounces of 30.594 g.

GENÈVE. (République de)

NOMS des POIDS ÉTRANGERS.	VALEUR EN								
	Grains de France.		Livres poids de marc de 9216 grains de France. (1)		Kilogram. de 18827 grains 15 centièmes. (2)	Hectogra. de 1882 grains 715 millièmes.	Décagra. de 188 grains. 2715 dix millièmes.	Grammes de 18 grs 82715 cent millièmes. (3)	Fraction de gramme.
	Grains	Fract.	Livres.	Fract.					
La livre vaut (5)............	8598	53	"	933	"	4	5	6	709

N.° 1. Pour convertir les livres poids léger de Genève en livres poids de marc, multipliez les livres poids léger de Genève à convertir par le nombre 0,9330002, et retranchez 7 chiffres sur la droite. Le produit sera la réponse.

N.° 2. Pour convertir les livres poids de marc en livres poids léger de Genève, multipliez les livres poids de marc par 1,0718111, et retranchez 7 chiffres sur la droite.

N.° 3. Pour convertir les livres poids léger de Genève en kilogrammes, multipliez les livres poids léger de Genève par 0,45670906, et retranchez 8 chiffres sur la droite.

N.° 4. Pour convertir les kilogrammes en livres poids léger de Genève, multipliez les kilogrammes par 2,1895778, et retranchez 7 chiffres sur la droite.

(1) Voyez la division de la livre poids de marc, chap. 8, art. 11, pag. 14.
(2) Le kilogramme est le poids du décimètre cube, ou de 50 pouces cubes 4124 dix millièmes, capacité du litre.
(3) 10 grammes font 1 décagramme; 10 décagrammes, ou 100 grammes, font 1 hectogramme, et 10 hectogrammes, ou 1000 grammes, font 1 kilogramme.
(4) Le peso casso vaut 6063 grains 19/100. Le peso grosso pour les grosses marchandises vaut 5981 grains 18/100. Le rubbo pour l'or, l'argent, etc., vaut 25 livres sotillis. Le rottolo vaut 25 pissis grossis. Le cataro vaut 6 rubbis grossis. Le rottolo poids de la douane vaut 10248 grains 19/100. Le rottolo vaut 1 pessi grossi 1/2. Le rottolo poids de caisse vaut 9259 grains 39/100.
(5) Poids léger. Cello poids pesant vaut 10303 grains 1/2 de Paris.

Conversion table for the Geneva and Parisian livres
Palaiseau, Métrologie universelle ancienne et moderne, Bordeaux 1816
History of science museum Library

A universal metric system

The kilogramme defined by terrestrial measurement

Following the example of the revolutionary metre, the kilogramme was defined as the mass of a cubic decimetre of pure water at a temperature of 40 °C. The kilogramme was the basis for the determination of a litre as the volume occupied by the mass of a kilogramme of pure water.

In 1799, a reference kilogramme (called the grave) was deposited at the Archives de France. It was a platinum cylinder 39.17 mm in diameter and in height. It was replaced in 1889 by a new alloy standard of 90 % platinum and 10 % iridium.

This prototype was used as the official definition until 2019. Until then, the kilogram was the only base unit of the international measurement system to be defined according to a material standard and not according to a natural invariant constant of matter.

Physicists have noticed over the years that the reference standard cylinder has lost weight (35 micrograms!) and weighs less than the official copies made at the same time and scattered around the world.

This tiny difference in weight may seem insignificant, but it can pose a problem in the new technologies of the infinitely small. After years of research, the kilogram has been redefined: it now depends on Planck's constant, which comes from quantum physics.

Les mêmes mesures de pesanteur, dans l'ordre progressif décuple, avec leurs équivalens en grains et onces de l'ancien système.

			Grains. millièm.		Onces.	deniers.	grains. milliem.
Le plus petit est le . . .	*milligramme*, .	*ou*	o'o19,	*ou*	o	o	o'o19.
Dix milligrammes font un	*centigramme*, .	*ou*	o'188,	*ou*	o	o	o'188.
Dix centigrammes font un	*décigramme*, .	*ou*	1'882,	*ou*	o	o	1'882.
Dix décigrammes font un	GRAMME, . .	*ou*	18'827,	*ou*	o	o	18'827.
Dix grammes font un . .	*décagramme*, .	*ou*	188'271,	*ou*	o	7	20'271.
Dix décagrammes font un	*hectogramme*,	*ou*	1882'715,	*ou*	3	6	10'715.
Dix hectogrammes font un	*kilogramme*, .	*ou*	18827'150,	*on*	32	16	11'150.
Dix kilogrammes font un	*myriagramme*,	*ou*	188271'500,	*ou*	326	20	15'500.

Suivant l'arrêté des Consuls du 13 *Brumaire an IX.*

Les mots {gramme, décagramme, hectogram., kilogramme, décigramme} pourront être traduits par les mots {*denier.*, *gros.*, *once.*, *livre.*, *grains.*}

Table of new weights
Téron, Instruction sur le système de mesures et poids uniformes pour toute la République française, Genève, 1802
History of science museum Library

Modern units

The constant properties of nature

The new revolutionary metre was not adopted internationally until 1875 when the Metre Convention was signed in Paris by 17 countries including Switzerland. The Convention established several organisations including the International Committee for Weights and Measures and the General Conference on Weights and Measures, mandated to standardise physical measures worldwide.

A new prototype metre standard was created in 1889. It was an x-rule made of an alloy of platinum and iridium, with a line one centimetre from each end. The distance between the two lines defines the metre.

In 1960, the Eleventh General Conference on Weights and Measures adopted the International System (SI) of Units composed of seven basic units – the metre, the kilogramme, the second, the ampere, the kelvin, the mole and the candela - with the objective of putting some order into the hundreds of units being used in the natural sciences. To ensure perfect consistency in time and space, the new units were defined according to constant natural physical properties and not to a material standard. Thus the metre equalled 1,650,763.73 the wavelength of light emitted by the krypton-86 isotope in a vacuum.

The metre was redefined even more precisely in 1983. Since that date a metre has been equal to the distance travelled by light in a vacuum for 1/299 792 458 of a second.

Standard metre
MHS 84
Brass, Lenoir, Paris, Early 19th century

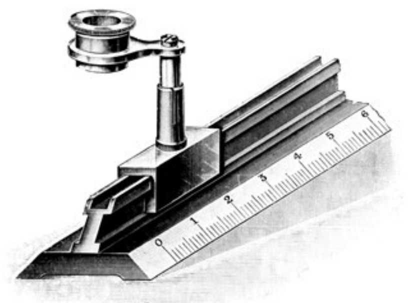
Copying the standard metre bar

A Geneva speciality

The signature of the Metre Convention in Paris in 1875 indirectly brought benefits to a young Geneva company, the Société genevoise d'instruments de physique (SIP) founded in 1862 by Marc Thury (1822-1905) and Auguste de la Rive (1801-1873). Originally created to supply instruments to the scientific community in Geneva, SIP turned towards a much more lucrative market – the manufacture of standard rulers.

From 1889, each of the signatory countries to the Convention received a prototype of the new standard metre. The prototypes were the models for copies or secondary standards used by industry. At that time, SIP already had a reputation in the field. A dividing engine invented by Marc Thury, meant that the SIP had been manufacturing various scaled bars and rulers (in yards or metres) for scientists for nearly 10 years. The company was therefore a natural choice for the manufacture of thousands of secondary standards.

The first metre standards produced by SIP were bronze, H-shaped bars. The scale is etched on a silver band set into the bronze at the cross-bar of the H. Later, the rulers were made of different iron and nickel (invar, platinite) alloys which are more stable than bronze. SIP continued to produce metal standards until the beginning of the 1970s.



Divided ruler for measuring maps
SIP, instruments et appareils de mesure,
Genève, 1921
History of science museum Library

Standard ruler
MHS 2230
Steel, nickel, SIP, Geneva, 1899

Standard ruler
MHS 2250
Steel, alloy, SIP, Geneva, 20th century

Dividing engine

An instrument for engraving rulers

The first dividing engine produced by SIP appeared in 1865. Produced by Marc Thury it engraves scales on a metal ruler. It is a narrow, mobile table on which the ruler to be marked is placed and which slides on an iron frame. The table is moved by a long horizontal guide screw fitted to a lock mechanism. At each rotation of the guide screw the table moves forward by one thread pitch. When the table stops, a diamond etching needle fitted to a scriber lowers itself onto the ruler to engrave a trace, then it rises and the cycle starts again. Errors in the guide-screw thread are identified automatically by an ingenious correction system. Thury's dividing engine allows scale divisions to an accuracy of one-tenth of a millimetre. Later machines reached an accuracy of one-thousandth of a millimetre.

In 1881, the SIP developed a circle dividing machine to etch scales on drums and round plates. One of its first tasks was to divide the circles of Emile Plantamour's large equatorial telescope (1815-1882) for the Geneva Observatory.

Dividing machine
MHS 2188
Steel, cast iron, brass, SIP, Geneva, about 1865

SIP and metrology

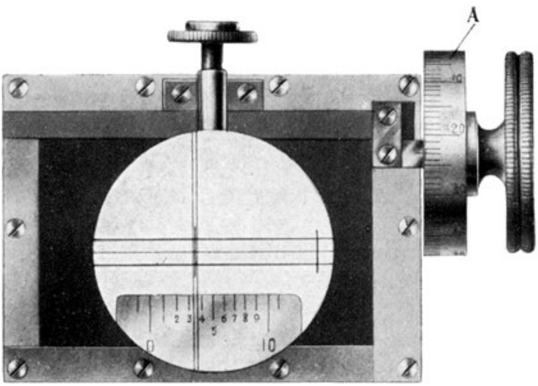
An obsession with precision

During the second half of the 19th century, in addition to dividing engines and rulers, SIP specialised in the manufacture of a wide range of measuring instruments: micrometric microscopes, measuring machines, comparators, triangulation mounts, etc.

Micrometric microscopes

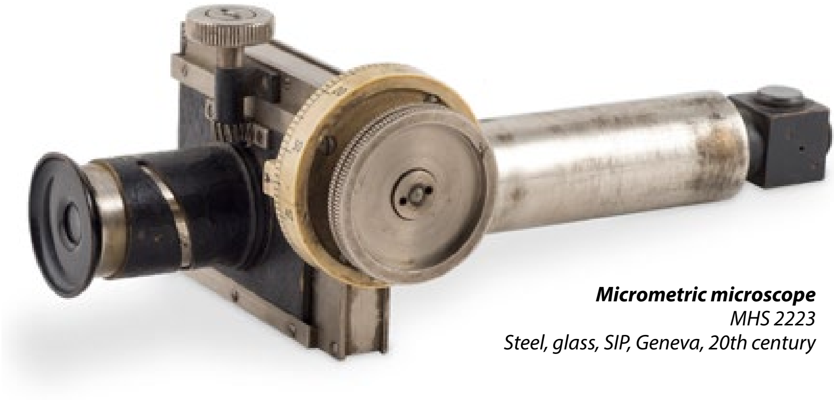
These were an indispensable accessory to dividing engines. They are equipped with scaled mobile markers at the eyepiece for verifying the precision of an engraved line. Until the 1940s, the markers were made of two spider's web threads separated by a standard distance (one tenth of a millimetre). The threads were collected from spiders' cocoons. Apparently only "thin spiders" offered the required quality. The threads were placed in a bottle to absorb humidity and swell before being stretched on a reticle.

The guidance system is moved by a micrometric screw controlled by a scaled drum. A full turn of the screw shifts the reticle by a distance equal to the distance between the two threads. The degree of displacement can be measured very accurately and therefore the exact position of each of



Part of the visual field of a mobile thread micrometric microscope
SIP, Instruments et appareils de mesure, Genève, 1921
History of science museum Library

the required markers. After the 1950s micrometric microscopes were gradually replaced by automatic photo-electric locators which dispense with the need for human operators.



Micrometric microscope
MHS 2223
Steel, glass, SIP, Geneva, 20th century

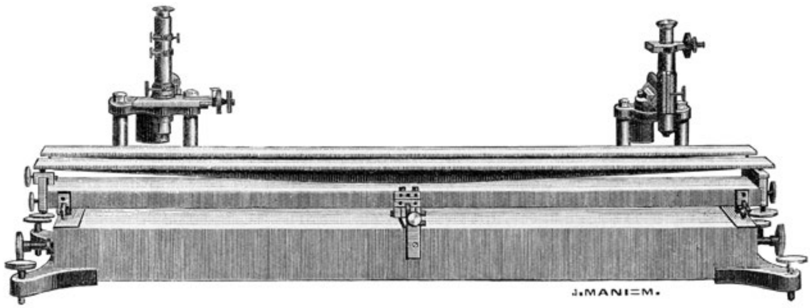
The spherometer

These instruments measure the curvature of lenses and spherical mirrors with the aide of a micrometric screw which moves vertically. The lower pointed end of the screw is placed on the curved surface to be measured. The rotation angle of the screw corresponds to a vertical shift which is indicated on a vertical ruler.

Spherometer
MHS 2647
Steel, SIP, Geneva, 20th century

The comparator

Comparators compare an unknown ruler with a standard ruler using a micrometric microscope. They are sometimes fitted with water troughs in which the rulers are immersed to ensure perfect thermal stability. During the measuring process, the two water containers are moved horizontally so as to bring the markers on the two rulers (the standard and the ruler being calibrated) within the viewing field of a micrometric microscope. Comparators also verify whether the sub-divisions of a single ruler are identical. The SIP manufactured several large instruments of this kind (4 metres long and weighing 20 tonnes) and exported them to various laboratories responsible for weights and measures in their countries.



Comparator for measuring scale marks
SIP, Instruments généraux de mesure, Genève, 1912
History of science museum Library

Measuring machine

In 1909, during a period when the SIP had a very good reputation, the company brought off a spectacular coup in the industrial equipment market with a new measuring machine. It was a portable measurement bench capable of verifying the dimensions of machine-cast pieces with the precision of a micrometre. The pieces to be checked are placed between two stylers, one fixed and the other mobile, connected to a sliding carriage by a precision dividing drum. The length is measured through a microscope focussed on a reference ruler incorporated into the machine.

Precise, easy to use and robust the SIP measuring machines rapidly became a great success. During the First World War they were used in arms and munitions factories before becoming essential equipment for manufacturers of bicycles, sewing machines and mass-produced motors for which precision was vital.

Measuring machine
MHS 2630
Steel, aluminium, cast iron, SIP, Geneva, 20th century

Chronology

Some dates in the history of the metre

1793 : the revolutionary metre, a new universal measurement, is defined as one ten-millionth of a quarter of the terrestrial meridian
1799 : a metre and a kilogramme deposited at the Paris Archives become the official reference for the new metric system
1801 : Switzerland receives a copy of the metre reference. A new law is passed establishing standard weights and measures across the country.
1862 : foundation of the Société genevoise d'instruments de physique (SIP) by Auguste de la Rive et Marc Thury
1865 : the SIP produces its first dividing machine
1875 : signature of the Paris Metre Convention
1887 : Switzerland adopts the metric system
1889 : new international prototypes of the metre and kilo
1909 : the SIP begins to manufacture measuring machines
1960 : adoption of the new International System (SI) of Units. The metre is defined as equal to 1,650,763.73 wavelengths of the orange-red emission line in the electromagnetic spectrum of the krypton-86 atom in a vacuum.
1983 : the metre is defined as "the length of the path travelled by light in a vacuum during a time interval of 1⁄299 792 458 of a second".
2019 : The kilogram is given a new definition. It now depends on Planck's constant, derived from quantum physics.

Further reading

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Fischer Stéphane & Frommel Bénédict, La SIP, du microscope à la machine-outil, Genève, 2006
Guedj Denis, La méridienne, Laffont, Paris, 1997
Office fédéral de métrologie, Metas, Unités de mesure, Berne, 2007
Société genevoise d'instruments de physique, La SIP 1862-1962, Genève, 1962

History of science museum booklets

The museum collections described in short thematic booklets

1. The skies of Mont Blanc: In the traces of Horace-Bénédict de Saussure (1740-1799), pioneer of Alpine meteorology.
2. Once upon a time, there was electricity: A history of electricity through the instruments at the History of science museum.
3. Sun time: Description and use of the main types of sundial exhibited at the History of science museum.
4. Seeing the infinitely small: Instruments at the History of science museum trace the history of microscopy.
5. Models of the universe: A brief history of celestial measurement through some of the astronomical instruments in the History of science museum.
6. Observing the sky: A brief introduction to astronomy and presentation of instruments from the first Geneva Observatory.
7. The Pictet Cabinet: The art of teaching science through experiment.
8. Jean-Daniel Colladon, Geneva scientist and industrialist.
9. From foot to metre, from marc to kilo: The history of weights and measures illustrated by emblematic objects in the History of Science Museum collection.
10. The beginnings of modern meteorology.
11. Tubes (and light bulbs) at the History of science museum.
12. The Villa Bartholoni.

Downloads available at: http://institutions.ville-geneve.ch/fr/mhn/votre-visite/site-du-musee-dhistoire-des-sciences/parcours-permanent/

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D'HISTOIRE
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