SAUSSURE HYGROMETER

Lerebours et Secretan

1835-1870

MUNCYT. CE1985/004/0039

The hair hygrometer, or Saussure hygrometer, named after its inventor, the Swiss naturalist, mountaineer, and meteorologist Horace-Bénédict de Saussure, is a meteorological instrument that allows the measurement of the relative humidity of the air: the amount of water present in the atmosphere in gaseous form or as tiny suspended droplets. It belongs to the so-called absorption hygrometers, which are based on the property that many organic substances have of lengthening in humidity and shortening in dryness, with hair hygrometers being the most commonly used due to the sensitivity of hair. Hair hygrometers use a tensioned hair: when the environment is humid, it lengthens, and when it is dry, it shortens. Changes in length are indicated by a needle on a relative humidity scale, which has been previously calibrated by exposing the hair to a completely dry environment and to another saturated with water vapor.

This particular specimen was manufactured by the prestigious Parisian firm Maison Lerebours et Secretan, specialized in the construction of highly precise optical and scientific instruments, between 1835 and 1870, when the house was at the height of its prestige, as evidenced by the fact that it supplied the Observatoire de Paris.

The most remarkable feature of this Saussure hygrometer is that it uses a human hair —other models used horsehair, which was what the inventor used in the prototype— tensioned and degreased to facilitate the absorption of environmental moisture. Specifically, this one has a blonde hair, which apparently deforms more consistently. The hair is attached to the frame at its upper end. The lower end is tied to a pulley, with an indicator needle on its axis, from which hangs a tiny weight: when humidity increases, the hair lengthens, causing the weight to rotate the pulley and its needle in one direction. If it shortens, the pulley and needle rotate in the opposite direction on the scale.

Since its invention in 1783, this type of hygrometer was widely used until the mid-20th century, when more precise instruments emerged.

THEODOLITE

George Adams

1755-1765

MUNCYT. CE1985/004/0354

The origin of the theodolite is uncertain. It is believed to date back to the 16th century, but neither the exact year nor its inventor is clear. In fact, it is possible that similar instruments were developed independently by different inventors around the same time. Some sources claim it was invented in 1615 by the Dutchman Snellus, based on the *quadratum geometricum*, an instrument developed by Tycho Brahe; other sources point to the British cartographer Leonard Digges as its inventor, or at least the creator of a precursor instrument, as early as 1551. This latter hypothesis is supported by the fact that Digges coined the term “theodolite” in his *Pantometria* of 1571, where he described a horizontal circle divided into 360 degrees, used to measure horizontal angles, a description that aligns much more closely with a simpler, more minimalist predecessor than with a classic theodolite like the one on display, crafted by the renowned optical and scientific instrument maker George Adams Sr. —whose son succeeded him as a master instrument maker— and who eventually became the instrument maker to King George III of England.

In any case, from its emergence, the theodolite became the instrument par excellence for precise angular measurements and thus a fundamental tool in astrophysics, geodesy, and surveying.

Beyond its apparent visual appeal, the key to its operation lies in the two perpendicular graduated rings or arcs on which the telescopic sight is mounted. These allow precise measurement of the angular distance covered by the sight in the vertical and/or horizontal plane. The screws allow the positions of both the sight and the graduated circles to be fixed: the sight is first aimed at one object or reference point, the origin of the circle is fixed at that point, and then the sight is moved to point at a second object. The position of the sight is fixed, and the angle indicated can then be read.

RAIN GAUGE

1870-1900

MUNCYT. CE1985/004/0932

In her essay "*The Infinity in a reed*" Irene Vallejo points out that the most perfect inventions are those that have undergone almost no changes since their creation, as is the case with the pencil or the book. In this category, the seemingly humble rain gauge should also be included, a meteorological instrument that appeared centuries before Christ and has essentially remained the same: it is basically a graduated container that allows the collection and measurement of the amount of rainfall over a given period of time in a specific area —or, more precisely, the number of liters per square meter.

Rain gauges arose independently in different parts of the world from ancient times: in India around the 4^{th} century BCE, in Asia Minor in the 1st century CE, and in China in the 13^{th} century. However, in Europe they are not recorded until 1639, thanks to the Italian Benedetto Castelli. It would not be until a century later that their use spread and became popular, driven by the growing interest in the newly established discipline of meteorology.

The instrument on display belongs to the category of conical rain gauges: these consist of two cylindrical bodies fitted together to minimize losses due to splashing or evaporation. The upper part is funnel-shaped or conical and serves to collect water and deposit it into the lower, graduated section, which allows for measurement. It is likely that the first conical examples were built in Prussia around 1717. It was also at that time that systematic rainfall measurements began, with periodic records of precipitation aimed at establishing annual climate patterns to improve agricultural production.

This rain gauge also falls into the category of non-recording instruments, as it only documents the total amount of water collected over a period of time, without showing how the precipitation evolved during that interval. Recording rain gauges —practically rain recorders or pluviographs— perform this task, documenting rainfall on a graph paper.

SURVEYOR'S CHAIN

1850-1930

MUNCYT. DE1995/022/0006
(DEPÓSITO DEL INSTITUTO GEOGRÁFICO NACIONAL; MINISTERIO DE FOMENTO)

Also called the Gunter's chain in honor of its inventor, the English clergyman and mathematician Edward Gunter, who conceived it around 1620.

The surveyor's chain is a distance-measuring instrument notable for its practicality: it compensates for its lack of precision and low sensitivity with great ease of use, making it ideal for measuring distances over uneven terrain and in applications where extreme accuracy is not required, such as surveying.

Its design could hardly be simpler, nor its use more intuitive: the chain consists of a series of rigid metal rods, each 20 cm long, connected by links and finished with a handle at each end. These handles, along with the intermediate links, allow the insertion of pins, which, when driven into the ground, keep the chain taut and prevent it from slipping. In practice, the chain was typically operated by two people: one at the front with a set of pins, inserting them as the rods were laid out, and another at the rear holding the end of the chain, collecting the pins, and keeping track of the distance. When the person at the front fully extended the chain before completing a measurement, they would wait for their companion to catch up before moving on and repeating the process.

The original chain was 22 yards, or 60 feet, long. A choice that now seems odd, but made perfect sense at the time: 10 chains equaled a furlong, 80 chains a mile, and an area of 10 by 10 chains corresponded to an acre. Moreover, the 22-yard length of Gunter's chain defines the exact length of a cricket pitch —a matter with which no Englishman would compromise.

ELECTROSCOPE

1853-1858

MUNCYT. CE1985/004/0375

Electroscopes are among the oldest tools in the scientific instrument arsenal, and also the first instrument for "measuring" electricity. Not surprisingly, the first electroscope was invented by the English physicist William Gilbert at the dawn of the 17th century to detect the presence of electric charge on a body. Its age explains its limited capacity (and the quotation marks around "measurement"), since it can only detect the presence of electric charge and, at best, provide a qualitative estimate.

Classic electroscopes fall into two main categories: the elderberry-sphere type, the first to be invented in 1754 by the British physicist John Canton, which were very simple and limited; and the gold-leaf type, developed in 1787 by the British physicist Abraham Bennet, which were more sophisticated and sensitive.

Interestingly, this model is a hybrid of the two: although it contains two elderberry spheres, its design and operation are directly related to the gold-leaf type. The elderberry spheres are located at the ends of two metal wires that hang from the top of a sealed glass bell, connected to a metal rod passing through the lid and topped by a metal ball. When a (presumably) electrically charged body is brought into contact with the ball, the charge flows along the rod to the two wires and finally to the surface of the elderberry spheres —an insulating material— which then acquire the same electric charge. This generates a repulsive force between the spheres, causing them to move apart, with the separation increasing as the charge increases.

The two vertical metal rods rising from the base serve a protective function: if the spheres were to touch the glass while separating, they could be damaged. These rods prevent that from happening, as contact with them allows the elderberry spheres to discharge and return to their original positions.

MICROSCOPE

John Cuff
1760-1770

MUNCYT. CE1985/004/0943

Microscopes, as we understand them —those we have all looked through at some point— are, strictly speaking, compound microscopes, meaning they have two or more lenses in their optical system. This contrasts with so-called simple microscopes, which were essentially high-magnification single lenses.

It is believed that the (compound) microscope was invented by the Dutch Jansen brothers, renowned makers of eyeglasses and lenses, who were the first to place two lenses at the ends of a hollow tube and observe that they magnified the smallest objects. However, the first practical or modern compound microscope is considered to be the one devised by Robert Hooke in 1603. Hooke's microscope is an example of a tripod microscope —so called because it was mounted on a stand rather than held by hand like a magnifying glass— and it consisted of three lenses, one in the objective and two in the eyepiece, as well as a light source to increase sample illumination.

The design of microscopes changed very little over the next two centuries. Evidence of this is this microscope, made by the prestigious manufacturer John Cuff. It is also a tripod —or stand— microscope, and, like Hooke's, incorporates three lenses in the tube and a system for illuminating the sample. The main difference is the focusing system: Hooke's used four concentric, extendable tubes, whereas this one uses a vertical micrometer screw that allows precise adjustment of the optical system's position.

The micrometer screw was introduced to microscopes by Cuff around 1745. In this specimen, it can be seen just behind the top end of the vertical support. If one looks closely, the support is composed of two bars, pillars, or flat pieces —one fixed and one movable— that slide against each other. The screw is attached at one end to the fixed bar and at the other end to the movable one, so turning it allows slight displacement of the movable bar and, therefore, fine adjustment of the optical system's position. This model is equipped with six objectives of varying magnification.

+INFO

BAROMETER

A. Masino & Co. 1840-1860

MUNCYT. CE1985/004/0017

The barometer, an instrument used to measure atmospheric pressure, was invented by Evangelista Torricelli in 1643 as an experimental setup: a narrow glass tube partially filled with mercury, with the upper end sealed and the lower end open and submerged in an open reservoir also filled with mercury. In this arrangement, the weight of the air column —that is, atmospheric pressure— determined the level of mercury in both the reservoir and the tube. When the pressure increased, mercury in the reservoir was pushed down, allowing some to rise inside the tube, causing the mercury column to ascend, and vice versa.

The use of this device as a practical measuring instrument emerged shortly afterward, when Blaise Pascal used it to measure pressure during his ascent of a mountain, confirming that it decreased with altitude. Meanwhile, Boyle and Hooke observed that it also varied with weather conditions, enabling short-term weather prediction.

This model belongs to the so-called "banjo barometers," named for their shape, reminiscent of the musical instrument. It is also a dial barometer and a siphon barometer —a direct descendant of Torricelli's barometer. It consists of a tube with a closed upper end, while the lower end forms a U-shape, with a second, much shorter branch open to the atmosphere and sensitive to air pressure, to which a system of counterweights and pulleys has been added. One of the weights floats on the mercury; as the pressure changes, the mercury rises or falls, moving the weight, which turns the pulley and transmits motion to the dial's indicator needle.

Banjo barometers appeared in the early 19th century, just as barometers were transitioning from purely meteorological instruments to highly prized and decorative objects

DIP NEEDLE

1900-1920

MUNCYT. DO 1995/031/0207
(DEPÓSITO DE LA FACULTAD DE CIENCIAS FÍSICAS, UNIVERSIDAD COMPLUTENSE DE MADRID)

A a dip needle, dip circle, dip compass or simply a device for measuring magnetic tilt, is precisely that: an instrument that measures the magnetic inclination at a specific location on the Earth's surface. But what is magnetic inclination? To understand it, one must start with the fact that the Earth behaves like a giant magnet, with two magnetic poles —the magnetic south pole and the magnetic north pole, the latter being the direction a traditional compass points to— and an associated magnetic field, evidenced by the existence of field lines running from one pole to the other. Magnetic inclination, therefore, is the angle formed by these magnetic field lines with respect to the Earth's surface. It ranges from 90° at the magnetic poles to 0° at the (magnetic) equator.

From this perspective, the design of the instrument makes perfect sense: a needle that, instead of rotating freely on a horizontal disc or housing as in a compass, moves along a vertical circle or semicircle, usually graduated and sometimes mounted on a support.

The utility of the instrument is equally clear: the angle indicated shows how close one is to the magnetic equator, whose exact location was, in fact, one of Humboldt's expedition objectives. At the same time, magnetic inclination at a known latitude provides clues about the nature of minerals in the soil, particularly their magnetism. If the measured inclination is greater than expected, it indicates the presence of another "magnet" nearby that is pulling on the needle.

The instrument on display consists of a graduated metal quadrant and a magnetized needle that can swing over the scale of the arc. To measure magnetic inclination, the graduated quadrant is aligned with the plane of the magnetic meridian —that is, the vertical plane running from one magnetic pole to the other. In this arrangement, the angle of the needle indicates the magnetic inclination at that location.

GRAPHOMETER

Vicente Comas

1690-1770

MUNCYT. CE1992/014/0007

A graphometer is an instrument for measuring horizontal angles, widely used in surveying for creating maps and topographic surveys of land and estates. It is generally used in combination with a surveyor's chain or another instrument that allows distance measurement, although it can also be used independently to calculate distances through triangulation.

While some sources suggest it may have been invented by the Italian mathematician Niccolò Fontana Tartaglia in the first half of the 16th century, most attribute its invention —at least in its best-known form— to the French engineer, inventor, and engraver Philippe Danfrie in 1597, the year he published *Declaration de l'usage du Graphometre*. Its design remained more or less unchanged for the next three centuries, during which it enjoyed great popularity, although many later models incorporated compasses. This is the case with the instrument on display, made by the optical and scientific instrument maker Vicente Comás, who established his workshop in Barcelona in the first half of the 19th century.

In its most common form, the graphometer consists of a rigid semicircle with its corresponding diameter, each end fitted with a sight. Mounted on the semicircle, at its center, is a movable rule called the alidade, which can rotate along the diameter and is also equipped with two sights. The entire assembly rests on a support with a base. Its operation is fairly intuitive: once positioned horizontally on the ground with the alidade placed over the diameter, one sights a reference point through the four sights, then rotates the alidade until the second reference point is visible through its pair of sights. The angle is then read from the scale engraved on the semicircle.

From the 19th century onward, many graphometers replaced the traditional sights —simple slots in a metal plate— with telescopic sights, equipped with magnifying lenses that allowed for aiming at more distant objects, thus extending their range and improving precision.

HYPSOMETER

Graselli y Zambra

1860-1880

MUNCYT. CE1985/004/0761

A hypsometer is essentially a thermometer used to measure atmospheric pressure and/or altitude. But doesn't a thermometer measure temperature? Yes, but the hypsometer operates based on the so-called Thermometric Principle of Hydrometry, proposed by Fahrenheit in 1724 and experimentally verified by De Luc in 1762. According to this principle, the boiling point of liquids in general, and water in particular, decreases as pressure decreases: at atmospheric pressure, water boils at 100°C. A variation of 0.04°C in the boiling temperature indicated by the hypsometer's thermometer corresponds to a 1 millibar change in pressure. Or, equivalently, each degree change in boiling temperature represents a 27 millibar difference in pressure.

At the same time, atmospheric pressure decreases with altitude, as Pascal had already demonstrated in 1648. Therefore, both pressure and altitude can be determined by measuring the temperature at which a sample of water boils.

However, it took almost a century before the hypsometer was invented, presumably by the French scientist Victor Regnault around 1850. To fulfill its dual purpose, the hypsometer features, as expected, a thermometer enclosed within a tubular chimney. At the base of the chimney is a reservoir to hold the liquid, with a flame burner located just beneath it. When the liquid is heated to boiling, the released gases rise through the chimney and surround the thermometer, which registers the boiling temperature. Using reference tables, this temperature allows the determination of both atmospheric pressure and altitude.

There is more: at a known altitude and pressure, the boiling point of a liquid mixture can also provide information about its composition. For this reason, hypsometers —later renamed pycnometers— have been widely used in wine and other alcoholic beverage production facilities to determine alcohol content.

SPYGLASS

By definition, all spyglasses are telescopes, but not all telescopes are spyglasses. Only refracting telescopes —those that use lenses in their optics— are considered spyglasses, in contrast to reflecting telescopes, which also incorporate mirrors.

This is a spyglass because it contains only four lenses in its tube: one in the objective, one in the middle section, and two in the eyepiece. These lenses are precisely the most remarkable feature of this instrument, as they constitute the achromatic system invented by John Dollond, who also manufactured this model.

In 1750, optics was embroiled in a debate between the opposing views of Isaac Newton and Leonhard Euler regarding the possibility of creating lenses that could eliminate chromatic aberration —the appearance of colored fringes around an image— by combining different types of lenses in telescopes. Newton had been the first to investigate this possibility and concluded that it was impossible. However, in 1747, Euler suggested that it was feasible. Dollond, as a true Briton, initially sided with Newton but decided to experiment with different lens combinations. This decision ultimately led him to invent the achromatic lens for telescopes. The design combined a concave lens made of flint glass with a convex lens made of crown glass, counteracting each other and thus eliminating chromatic aberration. He published the results in 1758 while simultaneously patenting his new achromatic lens, securing exclusive manufacturing rights.

From that moment on, Dollond telescopes and spyglasses —the only instruments equipped with his achromatic lens— became highly sought after and famous. From Frederick the Great to Thomas Jefferson, everyone wanted one. On his expedition to observe the transit of Venus in the Pacific, Captain Cook carried a Dollond spyglass on board, in addition to a Short reflector telescope. In fact, during the second half of the 18th century and part of the 19th century, the term "Dollond" became widely used as a synonym for telescope.

TELESCOPE

James Short
1755-1765

MUNCYT. CE1985/004/0165

Refracting spyglasses, or telescopes, were probably invented by the Dutch lens and eyeglass maker Hans Lippershey around 1600. However, reflecting telescopes —those that incorporate mirrors as part of their optics— were not invented until 1672 by Isaac Newton, when he replaced the usual lenses with concave mirrors inside the tube. The mirrors allowed for better focusing and avoided aberrations. They also improved magnification, since it is easier to manufacture a large concave mirror than an equivalent lens.

This portable telescope is a descendant of Newton's original design. As such, it contains two mirrors in addition to two lenses in the tube: near the eyepiece is a concave mirror with a central hole, and at the opposite end is another mirror of smaller diameter. When the objective is uncovered, light enters through the space between the tube and the mirror until it reaches the rear mirror, which reflects the rays onto the smaller mirror. This mirror further concentrates the rays and directs them through the hole in the first mirror to the eyepiece lens. Focusing is achieved using a rod at the bottom of the tube, which moves the mount of the smaller mirror via a screw.

As indicated by the inscription near the eyepiece —"JAMES SHORT LONDON 84/641 =18"— this instrument was made by the Scottish optician James Short, one of the most renowned makers of optical instruments of his time. The prestige and precision of his telescopes is evidenced by the fact that they were chosen to travel aboard the *HMS Endeavour,* commanded by James Cook, for observing the Transit of Venus from Tahiti in 1769.

The inscription also specifies that this is a telescope with an 18-inch focal length —specifically, instrument number 84 with this characteristic out of the 641 he had produced up to that date, a total that would eventually rise to 1,360 over the course of his career.

MARINE CHRONOMETER

Ferdinand Berthoud

1787

MUSEO NAVAL DE MADRID. MNM1332

Between the 16th and 18th centuries, the development of an effective system for determining longitude at sea became the greatest challenge and objective of the European naval powers. In theory, it was a straightforward problem: knowing that there is a one-hour difference between two consecutive meridians, which are 15° apart, it would be enough to compare local time (on the ship) with the time at a reference meridian to calculate longitude. By then, pendulum clocks were already sufficiently accurate. The problem was that they became inaccurate due to the constant, irregular, and often extreme motion of the ship, as well as changing weather conditions, making it impossible to know the reference time.

The solution was not achieved until 1759, when after years of arduous work, the British clockmaker John Harrison built his H4 chronometer, capable of keeping time on board with an acceptable deviation of just 3 seconds per day. This was possible because it used a balance wheel regulated by a torsion spring, which was much less affected by the ship's motion and changing conditions than the weights and pendulums that regulated conventional clocks.

The H4, a marvel roughly the size of a large pocket watch, was presented to the Royal Society in 1760. A delegation of French horologists traveled to London to study it. Among them was Ferdinand Berthoud, who in 1775 built the first marine chronometer for the French Navy. Berthoud produced only 21 chronometers, including the eight commissioned by the Spanish Navy and delivered between 1775 and 1776, one of which is the piece on display in this exhibition.

It was during the second half of the 18th century that mass production of marine chronometers began. While in 1760 there were only four examples in the world (the H4 being Harrison's fourth prototype and the first fully operational), by 1815 there were over 5,000, and nearly all ocean-going ships carried at least one.

GEOLOGIST'S CASE

Around 1850

MUNCYT. CE1985/004/0213

Portable laboratories originated between the 17th and 18th centuries, driven by the great scientific expeditions of exploration and discovery, and by the growing interest in measuring, classifying, and analyzing the natural world and its phenomena.

These long expeditions could last several years, so the naturalists and scientists participating felt the need to carry all the necessary instruments with them, as Humboldt did. Moreover, they needed to equip themselves with a minimal portable laboratory —often in the form of a case or small suitcase— that could always be carried, containing the essentials for taking measurements and conducting analyses.

One of the pioneers in their use was probably Lavoisier, who in 1767 undertook a four-month horseback journey through the Vosges to classify minerals for the Atlas of Mineralogy, which he was preparing with Jan Guettard. For this purpose, he equipped himself with a small portable laboratory containing thermometers, a barometer, a hydrometer, and various reagents.

The use of these portable laboratories (and their name) spread and became common among scientists during the 18th century, standardized as cases or small suitcases containing basic reagents and small instruments. Johann Friedrich Göttling, a chemistry professor at the University of Jena, designed several models, the sale of which allowed him to supplement his salary, and they were very successful. It is therefore quite likely that one of Göttling's models was the one Humboldt took with him on his expedition, especially considering that he was already familiar with them, having begun his career as a mining inspector for the Prussian government.

The geologist's case on display is a perfect example of this type of portable laboratory, allowing a considerable amount of material to be carried in a compact space. It contains files, hammers, a Nicholson hydrometer for calculating densities or specific gravities, and a blowpipe for analyzing mineral samples and identifying their elements by comparison with standard samples contained in the glass containers.

CYANOMETER

Without a doubt, the cyanometer is one of the most poetic scientific instruments —if not the most poetic— since it is used to measure the degree or intensity of blue in the sky. This was an obsession for its inventor, the Swiss meteorologist Saussure, whose passion for nature had been instilled in him from a young age by his brother-in-law, the botanist Charles Bonnet. In fact, his fixation was not limited to the color blue; it extended to everything measurable in nature. And if there was no way to measure it, he invented a new instrument to achieve his goal. Thus, in addition to the hair hygrometer that bears his name, he invented a magnetometer, an anemometer, a heliometer to measure atmospheric warming from direct sunlight, and another instrument closely related to the cyanometer: the diaphanometer, which measured the transparency of the sky. In fact, the cyanometer and diaphanometer are so closely related that he invented both simultaneously in 1789.

The cyanometer is based on a design as effective as it is simple: a ring divided into 52 numbered segments, each dyed with a suspension of Prussian blue pigment in a different shade, ranging from white to black. To measure the degree of blue in the sky, one simply looks at the zenith from a specific distance from the eye through the ring and finds the segment that matches the color of the sky.

Why was determining the shade of blue so important to Saussure? Because he concluded that it depended on the atmospheric moisture content. The definitive explanation of the sky's color would be provided a century later by Lord Rayleigh, as a result of light scattering by atmospheric molecules and particles —including the tiny suspended water droplets that give the air its humidity.

Perhaps the greatest popularizer of the cyanometer was Humboldt —Prussian as the pigment itself— who made it one of his essential instruments. As a result, during his ascent of Chimborazo, he recorded a sky measuring 46 degrees of blue —the most intense ever documented.