Dalencé's Thermometer 1688.

Evolution of the Thermometer

1592-1743

—BY—

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EVOLUTION OF THE THERMOMETER

I. THE OPEN AIR-THERMOMETER OF GALILEO.

Discoveries and inventions are sometimes the product of the genius or of the intelligent industry of a single person and leave his hand in a perfect state, as was the case with the barometer invented by Torricelli, but more often the seed of the invention is planted by one, cultivated by others, and the fruit is gathered only after slow growth by some one who ignores the original sower. In studying the origin and tracing the history of certain discoveries of scientific and practical value one is often perplexed by encountering several claimants for priority, this is partly due to the circumstance that "coincidence of independent thought is often the cause of two or more persons reaching the same result" about the same time; and partly to the effort of each nation to secure for its own people credit and renown. Again, the origin of a prime invention is sometimes obscured by the failure of the discoverer to claim definitely the product of his inspiration owing to the fact that he himself failed to appreciate its high importance and its utility. The task of sketching the origin of the thermometer is fraught with similar difficulties; the actual inventor is known only at second hand, its development from a crude toy to an instrument of precision occupied more than a century, and its early history is encumbered with erroneous statements that have been reiterated with such dogmatism that they have received the false stamp of authority.

One of the most persistent of these errors is the assertion that the thermometer was invented about the year 1608 by a Hollander named Cornelius Drebbel. Wohlwill and Burckhardt have shown how this blunder originated. In 1624 a book was published at Pont-à-Mousson, entitled "La Récréation Mathématicque," over the pen-name A. van Etten, but written by the Jesuit Father Jean Leurechon, in which the author describes and figures a "thermometer, an instrument for measuring degrees of heat and cold that are in the air." The book was popular, passed through many editions and was translated into several languages; Casper Ens inserted in his "Thaumaturgus mathematicus," published at Cologne in 1651, a translation of the "76th Problem" of Leurechon, containing an account of the thermometer, and added to the word "instrumentum" the adjective "Drebbelianum." Reyer, Sturm, and others copied the phrase and it was incorporated in an article published in the "Journal des Sçavans," 1678, thus becoming a part of authoritative literature.

Ten years later, Dalencé, drawing his inspiration from the "Journal des Sçavans," published an attractive, illustrated volume entitled "Traittez des baromètres, thermomètres, et notiomètres, ou hygromètres, Amsterdam, 1688;" in this he wrote: "The thermometer was invented by a peasant of North Holland, named Drebbel," and he added that Drebbel was "called to the court of King James where he also invented the microscope." This statement was accepted by the Dutch savants Boerhaave and Musschenbroek, the French Abbé Nollet and others, and on their authority has been repeated over and over again, so that until very recently all encyclopedias, dictionaries of science and historical essays in natural philosophy adopted without reservation the phrase:

"the thermometer was invented by Drebbel." And yet it is easy to show that the Hollander had no part in the invention and never claimed it, and that the error originated in the misinterpretation of a simple experiment desçribed by Drebbel in a treatise on the "Elements."

Cornelius Drebbel, born in Alkmaar, Holland, 1572, was as alchemist who claimed to have discovered perpetual motion, and acquired sufficient reputation for learning to be invited to the court of James II, King of England; to him he dedicated his treatise on *Primum mobile* in 1607. Later in life he visited Prague where Rudolph had gathered famous alchemists, astrologers, and magicians, as well as more reputable astronomers, artists, antiquarians, and skilled mechanics; Drebbel, however, was unsuccessful in sustaining his claim to the discovery of perpetual motion, and Emperor Rudolph threw him into prison, from which he was released 'ere long by the death of the monarch, in 1612.

I have in my private library two copies of Drebbel's rare little volume, one in Dutch bearing the title: "Van de elementen quinta essentia en primum mobile, Amsterdam, 1709," and with a second title-page having the words:

"Grondige oplossinge van de natuur en eyggenschappen der elementen, Amsterdam, 1732." The other copy is in German and bears the date 1715. (Poggendorff, the German historian of physics, admits never having seen an edition of this treatise by Drebbel.)

The Dutch version contains a full-page woodcut representing a retort hanging by a chain from a hook in a beam, the mouth of the retort is under water in a basin, and beneath it is a fire; on the surface of the water are seen bubbles of air issuing from the retort; the whole is observed by two men in out-door costume. The text accompanying this picture, when translated, reads as follows: "Heat makes air and water subtle and light; cold, as the opposite of heat, makes them smaller and presses them together and condenses all the air that the heat had made to rise, as may be clearly shown when a glass retort is hung with the mouth in a bucket of water and fire is placed under the belly. We shall then see that as soon as the air in the glass begins to get hot, that air rises out of the mouth of the retort, and the water gets full of bubbles, and this continues so long as the air gets hotter; but if the fire be removed from beneath the retort and the air begins to cool, then the air in the retort gets thicker and heavier, so that the retort fills with water, and if the glass was made very hot the water will completely fill it."

This simple experiment merely shows the expansion of air by heat and its contraction by cold, and there is no question whatever of measuring the amount of heat; besides, Drebbel had been anticipated by Hero of Alexandria, who described essentially the same phenomena 1,750 years before, and by Drebbel's contemporary della Porta.

Giambattista della Porta of Naples, the precocious author of "Magia Naturalis" (1558), is sometimes credited with the invention of the thermometer, owing to a passage in his book "I tre libri de spiritali," published at Naples in 1606. In this work he describes an experiment devised to measure the expansion of air when heated by a fire; the arrangement described is the same as Drebbel's retort and basin, but the cut accompanying the text shows an inverted matras with its mouth under water; Porta marked on the tube with pen and ink the highest and lowest points of the water-column, but he does not seem to have used the instrument as a heat-measurer.

The word "thermoscope" first appears in print in the treatise "Sphæra mundi, seu Cosmographia demonstrativa," written in 1617 by Giuseppe Bianconi and printed at Bologna in 1620.

The word "thermometer" is first found in Leurechon's "Récréation mathématicque," (1624) already mentioned; his description of the instrument is the earliest that gives a clear notion of those in current use at the beginning of the seventeenth century, and is marked by charming simplicity of language.

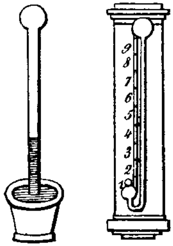
"It is an instrument of glass which has a little bulb above and a long neck below, or better a very slender tube, and it ends beneath in a vase full of water, or it is curved behind and has another little bulb into which water or any other liquid may be poured . . . It is used thus: Put into the vase below some liquid colored blue, or red, or yellow, or other color not too dark, like vinegar, wine, or reddened water, or *aqua fortis* which has been used to etch copper. Having done this, I say in the first place that as the air enclosed in the bulb becomes rarefied or condensed the water will plainly ascend or descend in the tube; this you can easily test by carrying the instrument from a very hot place to a very cold one. But without disturbing its position, if you lay your hand gently on the upper bulb, it is so sensitive and the air is so susceptible to every impression, that you will instantly see the water descend, and on removing the hand the water will return to its place. It is still more sensitive if one warms the bulb with his breath, as if one wished to speak a word into its ear to command the water to descend.

"The reason of this motion is that the air heated in the tube rarefies and dilates and wishes to have more room, and therefore presses upon the water and makes it descend. On the other hand when the air is cooled and condenses it begins to occupy less space and fearing to leave nothing but a vacuum, the water ascends at once.

"I say in the second place that by this means one can know the degrees of heat and of cold that are in the air at each hour of the day, the air that is enclosed in the bulb rarefies or condenses, ascends or descends. Thus you see in the morning the water stands quite high, and it descends little by little up to midday; towards vespers it remounts. Thus in winter it ascends so high that it nearly fills the tube;

but in summer it descends so low that in great heat it can scarcely be seen in the tube.

"Those who wish to determine these changes by numbers and degrees draw a line all along the tube and divide it into eight degrees, according to the philosophers, or into four degrees according to the physicians, subdividing each of the eight spaces into eight others so as to make sixty-four little ones. And by this means they can determine to what degree the water ascends in the morning, at midday and at every hour. Also one can determine how much colder one day is than another, noting how many degrees the water ascends and descends. One can compare the greatest heat and cold of one year with those of another year. One can ascertain how much hotter one room is than another; one can maintain a room at an equal temperature by making the water of the thermometer stand always at a certain degree. One can test also the intensity of fevers; in short, one can know pretty nearly to what extent air is rarefied in the greatest heat, and so forth."



Leurechon's thermometers.

This interesting account is accompanied by two illustrations, copies of which are here given.

Credit for the invention of the primitive form of the thermometer really belongs to the famous Italian physicist and astronomer Galileo Galilei, notwithstanding he made no claim to having devised the instrument and his extant writings contain only a casual allusion to it. It must be remembered, however, that most of the manuscripts of Galileo have been lost; many were consigned to the flames by his own grandson, Cosimo, and those rescued by his pupil, Viviani, were edited only in part, the precious originals being scattered by the ignorant persons into whose possession they came. In the voluminous correspondence that Galileo carried on with contemporary savants, there is abundant evidence that he was the inventor of the thermometer, that he used it in scientific research and labored to improve its efficiency, as he had done for the pendulum, the compass, the telescope, and the microscope.

Viviani, in his Life of Galileo, published in 1718, says that about the time Galileo took possession of the chair of mathematics in Padua, which was at the end of the year 1592, he invented the thermometer, a glass containing air and water which served to indicate changes and differences in temperature, an instrument afterwards perfected by Ferdinand II, of Tuscany. This assertion is confirmed in letters addressed to Galileo by his friend Francesco Sagredo, of Venice, and made public by Nelli in his biography of Galileo. The first of these letters is dated 9 May, 1613. Sagredo writes: "The instrument for measuring heat, *which you invented*, I have made in several convenient styles, so that the difference in temperature between one place and another can be determined up to 100 degrees." And he then gives examples of phenomena that he has examined by the aid of the instrument.

Two years later, 7 February, 1615, Sagredo wrote to Galileo more fully: "The use of the instrument for measuring heat and cold has been improved by me, and I think there is opportunity for many observations, but without your cooperation I had hardly succeeded. With this instrument I see clearly that the water of our fountain is colder in winter than in summer, and I imagine that the same is true of springs and subterranean places, although our feelings seem to indicate the contrary. . . .

During two snowstorms my instrument in a room here showed 130 degrees more heat than it indicated two years ago during extreme cold; on plunging the instrument into snow it indicated 30 degrees less, therefore only 100, but immersed in snow and salt, it showed a further 100 degrees less, and I believe in reality it marked still less but the snow and salt prevented it being seen clearly. In the greatest heat of summer the instrument stood at 360 degrees, and hence it appears that snow and salt increase the cold about one-third of the difference between extreme heat of summer and extreme cold of winter, a remarkable fact the reason for which I cannot determine. I shall learn with pleasure your opinions, especially what you have observed of the cold produced by saltpetre, of which I have heard many things, but have not personally seen. It will be difficult to send the instrument direct to you; it would be easier, I think, to have one made there."

A month later (15 March), Sagredo wrote to Galileo: "I have daily altered and improved the instrument for measuring temperature; if I could speak with you in person I could tell you from the beginning the whole history of my invention, or rather of my improvements. But since, as you write to me, and as I steadfastly believe, you are the first to discover and make the instrument, I suppose that those made by you and your excellent workmen are superior to my own; therefore I beg you at the first opportunity to write to me how you have them made, and I will report to you more or less of what is happening here."

In a long letter to Galileo, written 11 April same year, Sagredo mentions the use of wine as well as of water in the thermometers, alludes to having them made at the glass works in Murano, near Venice, and describes the construction of the best and most perfect of his instruments. This was made of a glass tube a finger wide joined to a bulb having a capacity of "three or four drinking glasses;" having made three of different sizes he watched their behavior during one year, sometimes as often as eight times a day, and he expresses wonder at their close agreement in both the extremes of cold and heat, the difference between them being not more than two or three degrees. He expresses surprise also at the great delicacy of his thermometers, which showed a difference of temperature when moved from the interior of a room to the open door, or on approaching them to a person or a lamp. He remarks at the same time that instruments made of thick and of thin glass do not change with equal rapidity, the thinnest moving the quickest; he also surmises that the unequal viscosity of water and of wine makes a difference. This interesting letter concludes with the remark: "Signor Gageo is in my room and disturbs me, and I do not want him to see what I am writing, so my letter will be disconnected for my mind is occupied in several ways."

The instrument Galileo used is described in a letter written by Father Castelli to Monsignor Cesarini, dated 20th September, 1638, in which he says it was used in public lectures thirty-five years before. Recounting what he remembers seeing, he writes: "Galileo took a glass vessel about the size of a hen's egg, fitted to a tube the width of a straw and about two spans long; he heated the glass bulb in his hands and turned the glass upside down so that the tube dipped in water held in another vessel; as soon as the ball cooled down the water rose in the tube to the height of a span above the level in the vessel; this instrument he used to investigate degrees of heat and cold." This lecture experiment dates from 1603.

In Galileo's extant writings there is only one reference to the thermometer and this corresponds in time with the letters of his friend Sagredo. In this fragment Galileo tries to explain the principle of the thermometer; he says that "when the air in the bulb contracts through cold, the wine in the stem rises to take the place of the void thus formed, and when the air is warmed it is rarefied and takes up more space so that it drives out and presses down the wine; "from this," says Galileo, "it follows that cold is nothing but absence of heat."

This correspondence and this fragment establish several things: 1st. The thermometer was invented by Galileo Galilei, between the years 1592 and 1597. 2nd. The instrument was an inverted air thermoscope containing either water or wine, and provided with a scale of degrees. 3rd. By its use Galileo determined relative temperatures of different places and of the same place at different seasons. 4th. Galileo made thermometric observations of freezing mixtures.

Galileo's method of graduating the stem cannot be ascertained, and was undoubtedly arbitrary, but the fact that he cites "degrees" prove that the instrument was of a higher type than some thermoscopes of even a later date.

Inverted air thermometers of this construction were, of course, subject to changes in atmospheric pressure, and were properly speaking "baro-thermoscopes," and no two of them were comparable. Sealed thermometers depending upon the expansion of liquids and independent of air pressure, were not made until fifty years later, and instruments with fixed points capable of accurate comparison were not devised until a century had elapsed.

The savants of Italy contemporary with Galileo naturally became acquainted with the great discoveries and inventions associated with his name, and the telescope from its marvelous revelations of celestial phenomena contributed the most to magnify his reputation; the great importance of the thermometer, on the other hand, was appreciated by comparatively few.

One of the colleagues of Galileo, Sanctorius Sanctorius Justipolitanus, who held the chair of the Theory of Medicine at the University of Padua from 1611 to 1624, applied the new instrument to physiological researches and described the results in several of his publications. The earliest of these references occur in his "Commentaries on the Medical Art of Galen," published in 1612, but written a year earlier, for the "license" is dated 9 June 1611. Nelli in his life of Galileo cites the following passage: "At last we have among us an instrument by which with a bulb we measure the withdrawal of heat from all the external parts of the body and of the air; by which we discover, very surely, how much more or how much less, daily, we differ from the normal [temperature]." Burckhardt cites this passage at second hand, transcribes the Latin erroneously, and says the sentence does not occur in the copy of Sanctorius' work found in the public library at Basel, and furthermore he satisfied himself that the volume contains no reference to any instrument for measuring heat; both these statements are undoubtedly correct so far as concerns the copy of Sanctorius which Burckhardt consulted, but I have found the passage in the copy of same date preserved in the United States Army Medical Library, Washington. The paragraph occurs in Part III, column 229, and this third part was probably wanting in the volume at Basel.

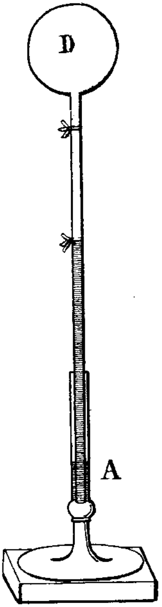
The historians of physics seem to have overlooked another passage of still greater interest which I discovered in the copy of Sanctorius at Washington. Translated it reads thus: "We determine the temperature by means of our glass instrument; we ascertain the high and the low (points) after this manner: we apply snow to the bulb of the glass instrument that the water may ascend to the highest point, then we approach the flame of a candle that the water may descend to the lowest point."

This important passage shows that Sanctorius appreciated the value of fixed points for graduation, and used snow and the heat of a candle to secure extremes. The division of the stem is unknown, but he mentions in one place (to be mentioned presently) "110 degrees."

One of the most celebrated books of Sanctorius is his "Medicina statica," published at Venice in 1614, and which passed through no less than eighteen Latin editions, besides two French versions, four English, one Italian, and one German. In the first edition occur the following interesting paragraphs: "How great the ponderousness of the air is, may in the *first* place be gathered from greater or less weight of the dregs of alum dried before in the sun and afterwards exposed to the air in the night time.

Secondly, from our feeling a greater cold than what is observable in the weather-glass (*instrumentum temperatorum*). For the moisture or ponderousness of the air is to us the measure of its coldness. *Thirdly*, from the greater or lesser bending of a very thin board, especially if it be of a pear tree. *Fourthly*, from the contraction of the strings of a lute, or from hemp." (Section II, Aphorism IV, English translation by J. D., London, 1678.)

In this "aphorism" Sanctorius mentions three hygroscopes and one thermoscope. Parenthetically, I call attention to the use of burnt alum and of a balance to determine atmospheric moisture quantitatively.



Sanctorius' thermometer.

The thermoscope used by Sanctorius is described by him in his "Commentaries on the first section of the first book of Avicenna," printed at Venice in 1646. In the preface to this the author says he has been engaged for fifteen years in preparing descriptions of his instruments, but the publication has been delayed by his duties as lecturer in the university. His apparatus resembled closely Galileo's, being a glass globe attached to a long narrow tube partially filled with water, which stood in a small open vessel of water; when the air in the globe is warmed the water in the tube sinks, and on cooling it rises. Sanctorius says the instrument "was used by Hero for other purposes, but I have applied it to the determination of the warm and cold temperature of the air and of all parts of the body, as well as for testing the heat of persons in a fever."

Sanctorius had the thermometer made in a variety of forms for taking the temperature of different parts of the body; in one style the bulb was inserted in the mouth of the patient and the long S-shaped tube was divided into degrees; when so applied the bulb was allowed to be in place during "ten pulse-beats." Sanctorius was the first physician to recognize that the human body has a normal temperature, and to determine variations from it as an aid to diagnosis. He also attempted to ascertain the heat of the moon, but misinterpreted his results; we now know that his instruments were not sensitive enough for the purpose. He made an experiment to measure the relation between the heat of the sun and of the moon, and recorded that in sunlight the water in his thermometer fell "110 degrees in two pulse-beats."

Before dismissing the connection of Sanctorius with the thermometer I note that the Italian physician nowhere claims to have invented it; on the contrary, he calls it in his "Commentaries on Galen" a "most ancient instrument." (P. 538, edition 1612.)*

II. THERMOSCOPES OF THE ACCADEMIA DEL CIMENTO.

Modifications and improvements of the thermoscope were probably made by many savants interested in their use, both in Italy, the birthplace of the instrument, and in all parts of Europe to which the knowledge of the invention penetrated, but few records of them have survived.

There is a manuscript preserved in the library of the Arsenal, Venice, entitled "Matematica meravigliosa," written by Telioux, a Roman engineer, in 1611, that is said by the historian

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* Prof. Cleveland Abbe suggests that this instrument had doubtless been used to illustrate the expansion of air by heat for a long time previous to Galileo, who simply added a scale for the use of Sanctorius so that the physician could express the intensity of fevers.

Libri (Histoire des sciences mathématiques en Italie, Vol. IV, p. 471, *notes*), to describe a thermoscope independent of atmospheric pressure. The instrument is said to consist of a bulb with a neck a foot or more long, nearly filled with water into which a smaller bulb-tube was inverted so that the neck was beneath the surface; Libri's account is accompanied by a drawing that does not correspond with the description and is obviously incorrect; whether the figure is from Telioux' manuscript does not appear, but if it is of the date 1611, it is the earliest representation of a thermometer with scale known to me. The scale attached to each side of the stem is divided into eight large spaces, and each space into sixty smaller ones, a division probably suggested by the graduation of astronomical instruments into degrees and minutes.

According to Poggendorff, Salomon de Caus, whose name is associated with the use of steam as a mechanical power, described a very imperfect thermometer in the work "Raisons des forces mouvantes," published at Frankfurt in 1615.

The eminent Englishman, Lord Chancellor Bacon, is sometimes put forward as the inventor of the thermometer, but he merely alludes to the instrument as if well known. In the "Novum Organon," 1620, Bacon describes an inverted "heat-glass," styled "Vitrum calendare," and says it bore "attached to the stem a long narrow strip of paper marked off with degrees at pleasure."

Attempts have been made by Italian authors to secure the credit of inventing the thermometer for another Englishman, Robert Fludd de Fluctibus, a physician and mystic whose books show more erudition than common sense. The Jesuit Franciscus de Lanis, in a work dated 1670, named Fludd as the original inventor, and Clemente, in his life of Galileo, 1793, has the contemptible effrontery to claim that Galileo in 1603 used an instrument made by Fludd. The facts are that about the year 1603 Fludd visited many countries of Europe, including Italy, where he may well have seen the Galileo thermoscope known to savants in Padua. Twelve years after Fludd's return to England, in 1617, he published a work (Utriusque cosmi . . . historia) in which he described an experiment chiefly borrowed from Hero, of Alexandria. In another work (Philosophia Moysaica) issued in 1638, a year after his death, Fludd describes a "Speculum calendarium," which was a simple thermoscope of the usual pattern, and says he found it in a manuscript more than 500 years old. This certainly disposes of the pretensions of those who claim Fludd as an originator.

The instrument figured in Fludd's book represents the usual inverted air thermoscope in a basin of water, the stem being divided into fourteen degrees, of which seven are below and seven above a central line named "sphaera aequalitis," a curious forerunner of our modern zero with plus and minus degrees.

The list of those to whom the invention of the thermometer has been ascribed should include the Servite monk Fra Paolo Sarpi, named by Fulgenzio for the honor; "Father Paul," as he is called, does not seem to have used the instrument before 1617, and does not mention it in his writings.

Before the days of academies of science and of periodical literature, communication between European savants was maintained by personal visits and by correspondence. One of the most active intermediaries between scientists in the first half of the seventeenth century was a French theologian, Father Marin Mersenne;

he was in constant communication with Galileo, Descartes, Gassendi, Roberval, Hobbes, and others, sending them news of discoveries and inventions in exchange for similar favors. Mersenne was also an experimenter, repeating and verifying the labors of others and thus familiarizing himself with every branch of physical science, but he made no noteworthy discovery; he was the originator of the custom of propounding prize questions, a scheme for stimulating scientific work afterwards adopted by certain learned societies. His "Récréations des savans" was published in 1634.

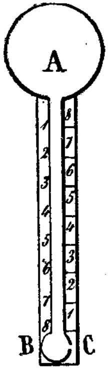
There lived at that time in Southern France an obscure physician named Jean Rey, who did two things in his lifetime that ought to have brought him renown, but he was in advance of the age and his discoveries were not appreciated by his contemporaries. Rey applied his knowledge of chemistry to the solution of the much vexed problem "why do lead and tin increase in weight when calcined?" In a book published on this subject in 1638, he gave the correct explanation, recognizing that the metals combined with a constituent of the air, and anticipating the grand truths that made Lavoisier famous 150 years later.

Secondly, Rey was the first to make use of the expansion of a liquid in the construction of a thermometer. In a letter written to Father Mersenne, 1 January, 1632, he said: "I observe there are divers kinds of thermoscopes and thermometers; what you tell me does not agree with mine, which is merely a small round flask having a very long slender neck. To make use of it, I put it in the sun, and sometimes in the hands of a fever patient, having filled it quite full of water except the neck; the heat expanding the water makes it ascend by a greater or less amount according to the great or little heat."

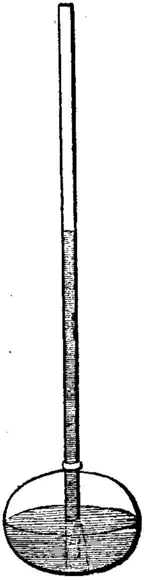
This evidently describes a water thermometer, or thermoscope, and so far embodied a new principle, yet it was still influenced by the pressure of the air. The instrument did not attract much attention.

Mersenne himself devised a modification of the air thermoscope intended to increase its delicacy, and described it in a work published at Paris in 1644, four years before his death (Cogitata physico-mathematica). The instrument consisted of a narrow tube having a large bulb at one end and a small one at the other, the latter being pierced with a minute hole;

by warming gently the air in the larger bulb while the smaller was plunged in water and then removing it, a few drops of the liquid rose in the graduated tube forming a short column of water that served as an indicator of changes of temperature. The graduation of the stem was peculiar; it was divided into eight degrees and these were numbered on one side from above downward, and on the other in reverse order.



Mersenne's thermometer



A. Kircher's thermometer.

In 1643, the learned Jesuit Athanasius Kircher published a quarto entitled: "Magnes, sive de arte magnetica," in which he mentions several thermoscopes. They have the usual form of the water-air instruments, but one is inverted making it convenient for testing the temperature of liquids. Kircher explains correctly the movement of the column of water caused by the expansion of the air, and adds the instrument indicates the goodness, the mildness, and salubrity of the air in different places, cultivated fields, plains or mountains, as well as the temperature of man in disease. He mentions a thermoscope containing mercury, but does not describe its construction; the text is accompanied by the figure of a thermoscope of which the stem is twisted into a spiral several feet in length. No reference is made to a scale. (Magnes, 1643, p. 515).

John Baptist van Helmont, a physician and chemist of Brussels, used in 1648 an air-thermometer similar in design to that of Leurechon, except that the stem had only a large drop of water, as in that of Mersenne. (Opera, 1648, p. 64.)

A most important and radical improvement in thermometers was made some time prior to 1654, by Ferdinand II, Grand duke of Tuscany, the liberal patron of literature and art, who devoted himself also to practical researches in physical science. Ferdinand made a thermometer of the usual form, filled it to a certain height with colored alcohol and then *sealed* it hermetically by melting the glass tip;* the

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* Rosenberger in his "Geschichte der Physik," (Braunschweig, 1882,) misunderstanding the alchemical expression "closed with Hermes' seal," says the tube was closed with *sealing-wax*.

closed instrument was then graduated by degrees marked on the stem.

This was the first thermometer independent of atmospheric pressure. Torricelli, it will be remembered, had shortly before invented the barometer and demonstrated the weight of the atmosphere. Tuscan savants and Blaise Pascal had applied it to the measurement of elevations. In constructing this new thermometer Ferdinand probably was guided by an experiment made by certain Florentine savants to show the influence of atmospheric pressure. The latter took a U-shaped glass tube open at both ends, on one arm of which two bulbs were blown, the uppermost ending in a very small open point; at the foot of a high tower the U-tube was filled to a certain point with liquid that reached the same height in both arms, and the open point was then closed by melting the glass, care being taken not to warm the air in the bulbs. The whole apparatus was then taken to the top of the tower and the liquid was seen to rise in the open arm and to sink in the closed arm owing to diminished pressure.

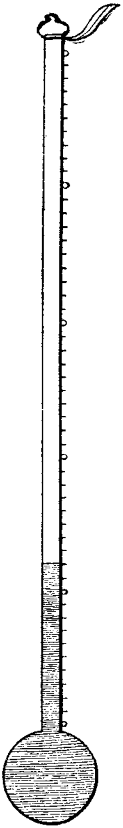
Ferdinand also applied the principle of the Cartesian divers to the construction of a thermometer, devising an entertaining apparatus (glass bulbs floating in a vessel of water), that puzzled many philosophers; in 1649 he sent one of these to Athanasius Kircher and one to Raphael Magiotti at Rome, with a challenge to explain the paradox, and both the Roman scientists published correct solutions. These instruments, of both the closed and the open forms, found many imitators, Guericke, Kircher, Dalencé, and Pasumot, but are not sufficiently accurate for thermometrical purposes.

In 1657 Ferdinand II, of Tuscany, and his brother, Prince Leopold de Medici, made a most valuable contribution to physical science in promoting the establishment in Florence of a society destined to become famous. The Accademia del Cimento, as its name indicates, was founded for the express purpose of ascertaining by experiment the facts and laws of nature; it numbered only nine members, most of them pupils of Galileo (who had died in 1642), besides a few foreign correspondents, and they devoted themselves to experimental research for truth's sake, taking as their motto "Provando e Riprovando." They did not even seek personal renown, for the results of their investigations were published in the name of the academy only, no individual being mentioned. The meetings were held in the palace of Prince Leopold, who also presided. The ecclesiastical authorities did not, however, approve of the enterprise, and the same power that persecuted Galileo caused the academy to be dissolved after ten years of useful activity.

The results or the members' joint researches were published in 1667 in a volume fascinating to the historian of science; the "Saggi di naturali esperienze fatte nell' Accademia del Cimento," which was translated into Latin and into English, the latter by Richard Waller, F.R.S., and published at London in 1684; this edition is the one used in these chapters.

Five instruments for measuring heat were described by the academy:

I. The first is described as a long tube having a spherical bulb and closed with "Hermes' seal" at the flame of a lamp. The tube is filled with "spirit of wine up to a certain mark on the neck, so that the simple cold of



Florentine thermometer.

snow or ice externally applied may not be able to condense it below the 20 degrees of the tube, nor on the contrary the greatest vigor of the sun's rays at midsummer to rarefy it above 80 degrees." The tube is divided into ten equal parts with compasses, each degree being marked with white enamel, and the ten intermediate divisions with green glass or black enamel. The academy preferred alcohol to water because it is "sooner sensible of the least change of heat and cold," and does not freeze in extreme cold. The alcohol is colored with solution of kermes, or of *sanguis draconis.*

II. The second instrument is "but a copy of the former in little"; the first being divided into 100 degrees and the second into 50. This comparison is then made:

	No. 1. Degrees.	No. 2. Degrees.
Greatest cold of winter	17 or 18	12 or 11
Excessive cold one year	8	6
Midday sun	80	40

III. The third thermometer is like the first but much larger, its length being 200 degrees. Of this the "Saggi" say: "We can lay down no certain rule to make it practice, often trials being the only way to effect it; by increasing and diminishing the size of the bulb or the bore of the cane, or the quality of the liquor, till at length it hits it right."

IV. The fourth thermometer had a very long tube bent in the form of a spiral, made "rather for fancy and curiosity to see the liquor run the decimals of degrees by the only impulse of a warm breath than for any accurate deduction." This instrument is styled a "very ticklish thermometer."

V. The fifth instrument was a wide tube of glass nearly filled wilh spirit of wine in which floated several little glass bulbs adjusted so as to sink to different points in the tube, as the temperature of the liquid rose. This instrument is evidently the same as that of Ferdinand previously noticed.

Although the "Saggi" of the academy were not published until 1667, there is abundant proof that many of the experiments and instruments therein described were devised many years earlier, some of them even before the birth of the academy. It is certain that the principles on which the thermometers were constructed were known in Florence as early as 1641, sixteen years before the academy was founded, and it is highly probable that thermometers Nos. 1 and 2 were made from the designs of the Grand Duke Ferdinand himself, for he used them in 1644 when he was experimenting on the artificial hatching of eggs, and in meteorological observations. In 1646 Torricelli showed thermometers of this construction to the distinguished French traveler, Monconys.

The members of the academy used these thermometers, especially the one of 50 degrees which they found the most convenient and accurate, in a variety of experiments with freezing-mixtures and the reflection of cold by a concave glass. The thermometer scales can be thus compared:

Academy thermometers.		Fahrenheit.
No. 1.	No. 2.	
73	37.5	96
19	13.5	32
− 8	− 8.5	0

In the year 1829 a number of Florentine thermometers were found in a shop in Florence by Antinori, and Libri ascertained their scales to have the following values: (Ann. chim., 45, 354).

Flor.	C.	Fahr.
13.5	0	32
0	18.7	65.6
50	55	131.

The academy's thermometers were a great

advance on the baro-thermoscopes that had preceded them, but their graduation left much to be desired; those of different lengths had degrees of unequal value, and individual instruments of the same pattern gave results only approximately similar. Their agreement depended on the skill of the workmen, who sought to get comparable thermometers by taking care to get tubes and bulbs equal in size, but they had no standard of graduation.

Florentine thermometers, made by skilful workmen, became famous throughout Europe; together with Torricelli's barometer and Ferdinand II's hygrometer, they were used at meteorological stations established by the Grand Duke, and conducted in Florence by Raineri, in Pisa by Borelli, as well as in Bologna, Parma, Milan, Warsaw, and Innsbruck; the instruments were observed several times daily and records were kept with great fidelity. One of the Italian day-books containing sixteen years' observations was examined by Libri in 1830, and he obtained evidence that the climate of Tuscany had not materially changed.

The meteorological observations made in Florence from December 15, 1654, to March 31, 1670, were published entire in the

"Archivio Meteorologico Centrale Italiano," Firenze, 1858, introduction.

The thermometers were introduced into France by the way of Poland; the Grand Duke Ferdinand presented some philosophical apparatus to the Envoy of the Queen of Poland, and her secretary sent one of the thermometers to the astronomer Ismael Boulliau in Paris, with the statement that Ferdinand always carried in his pocket a small one about four inches long.

Meteorological observations were carried on in Paris from 1670 with an instrument made for De la Hire by Hubin. The scale was arbitrary, but the thermometer was preserved until those with reliable scales were manufactured, and its values determined by comparison, thus permitting the records to be adjusted.

Florentine thermometers continued to be manufactured for general use in the eighteenth century; G. Reyger records that Hanow, in his observations of the weather in Danzig made in 1741, reported temperatures in degrees of the "usual Florentine scale, the 0 being in the middle of the tube, indicating temperate air, or 45 Fahrenheit." A. Momber also states that many thermometers made in Danzig as late as the middle of the eighteenth century had three scales, Réaumur, Fahrenheit, and Florentine; one of these is in the possession of the Naturforschende Gesellschaft of Danzig. Réaumur, writing in 1730, speaks of Florentine thermometers as in common use.

III. ATTEMPTS TO OBTAIN A STANDARD SCALE FROM BOYLE TO NEWTON.

Through whom knowledge of the thermometers devised by the Florentine Academy reached England is not known, but it has been suggested that the French traveler Monconys conveyed it to the Hon. Robert Boyle on the occasion of his visit to London in 1663, and there is circumstantial evidence in favor of this view. Monconys was most politely received by the scholarly Irishman and attended a meeting of the Royal Society on the 30th of May; he had with him in London one of the new instruments and made an entry in his diary on the 31st May to this effect: "The weather was cold towards evening and the thermometer fell to 6.5 degrees."

While the Accademia del Cimento was busy experimenting on heat and cold, magnetism and acoustics, and trying to prove the "nonexistence of positive levity," the British philosopher was working in similar fields; he improved the air-pump (invented in 1650 by Otto de Guericke), devised "physico-mechanical experiments touching the spring of the air," discovered the fundamental truth known as "Boyle's Law," invented the manometer, and made a great variety of observations in chemistry and physics of prime importance. All this work qualified him for thermometrical studies, and it is said that he constructed a "sealed weather-glass" before he saw the Italian instrument, but this is improbable.

Boyle graduated the stems of thermometers with "little specks of amel" into inches and fractions as small as sixteenths; in one experiment he found that "sal-armoniac" dissolved in water "made it descend to 2-11/16 inches in a quarter of an hour. He observed that thermometer stems were not sufficiently even and cylindrical, being often widest near the bulb, and said this was a source of inaccuracy.

Boyle felt the need of a standard permitting comparison of effects shown by different thermometers, and expressed it thus: "We are greatly at a loss for a standard whereby to measure cold. The common instruments show us no more than the relative coldness of the air, but leave us in the dark as to the positive degree thereof; whence we cannot communicate the idea of any such degree to another person. For not only the several differences of this quality have no names assigned them, but our sense of feeling cannot therein be depended upon; and thermometers are such very variable things that it seems morally impossible from them to settle such a measure of coldness as we have of time, distance, weight, etc." (1665).

Boyle endeavored to overcome this difficulty; believing that the melting-point of ice varied with geographical latitude, he proposed using the oil of aniseed for getting a fixed point, placing it around the bulb of an alcohol thermometer, allowing the oil to freeze and marking the height of the spirit of wine in the bulb "when the oil begins to curdle."

This scheme for getting a fixed point has been wholly misunderstood by some historians who state that Boyle filled his thermometers with aniseed oil!

While Boyle tried to secure one fixed point he overlooked the advantages of having two; he strove to compute the absolute expansion of alcohol and to divide the scale into ten thousandths, or some aliquot part of the total expansion.

Strange notions of natural phenomena were current in Boyle's day and the "Father of Chemistry" was not above crediting absurdities; he quoted Orthelius who wrote: "The liquor distilled from the ore of magnesia, or of bismuth, will swell considerably in the glass it is kept in at the full moon, and subside at the new."

Contemporary with Boyle, another distinguished British philosopher was occupied with improvements in thermometers. Robert Hooke, afterwards secretary of the Royal Society, published in 1664 his "Micrographia;" in this work he says: "I have brought sealed thermometers to a great certainty and tenderness, for I have made some with stems above four feet long in which the expanding liquor would so far vary as to be very neer the top in the heat of summer and preety neer the bottom at the coldest time of winter." Hooke filled his thermometers with "best rectified spirit of wine highly ting'd with the lovely colour of cochineal." To graduate the stem he placed zero at the point which the liquid stood when the bulb was placed in freezing distilled water; he then marked the divisions above and below "according to the degrees of expansion or contraction of the liquor in proportion to the bulk it had when it indur'd the freezing cold."

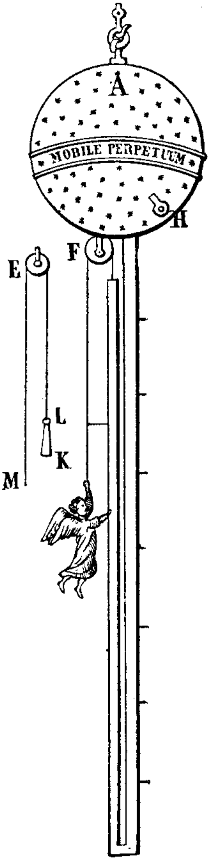
Edmund Halley, writing in 1700, said that Hooke exhibited at Gresham College, 2nd January, 1667-8, a combination of barometer and thermometer in separate tubes, the freezing-point of water being equal to zero, and the stem being graduated from -70 to $+130$.

Hooke made an important step in advance when he took the freezing-point of water as a fixed point in the scale, but the statement made by Brewster that in 1684 Hooke proposed the boiling-point as a second fixed point has been examined by Poggendorff and not verified. The claim has been made that the two fiduciary points were first proposed by the Dutch mathematician Christian Huyghens, in a letter dated 2nd January, 1665, addressed to Robert Moray. (A. Momber, Schr. naturf. Gesch. Danzig, N. F. VII, 108.) Huyghens wrote: "It would be well to have a universal and determinate standard for heat and cold, securing a definite proportion between the capacity of the bulb and the tube, and then taking for the commencement the degree of cold at which water begins to freeze, or better the temperature of boiling water, so that without sending a thermometer to a distance, one could communicate the degrees of heat or of cold found in experiments and record them for the use of posterity." In this passage Huyghens does indeed suggest the two phenomena for fixing a standard, but only as alternatives, and he seems to have had no idea of dividing the space between them.

The proposition to divide into equal parts the interval between two points to be ascertained by experiment was made four years later by Honoré Fabri, a Jesuit of French birth, who had been one of the corresponding members of the Accademia del Cimento. In his voluminous work on physics published in 1669, he describes an experiment with a Florentine thermometer for the purpose of constructing such a scale; he applied snow in very cold weather to the bulb and marked the point at which the liquid stood, then he marked the position of the liquid at the highest heat of summer and divided the line drawn between these points into eight equal parts. As we now know, the higher fixed point was ill-chosen, but the method was correct in principle, though not adopted until long after. Meteorological observations were made with Hooke's thermometers by John Wallis, professor of mathematics in Oxford University, and he recorded in a certain paper published in the *Philosophical Transactions* for 1669, (p. 113), that the "liquor" stood at three and one-half inches on December 26, 1669, and at seven inches in "brisk frosts."

Several novel forms of thermometers were constructed about 1660–62 by the accomplished experimenter in physics, Otto de Guericke, Burgomaster of Magdeburg; they all bore impress of his genius, and one of them was, and still remains, unique in many particulars. It was gigantic in size being above twenty feet long, gorgeous with blue paint and gilt stars, and decorated with the image of a winged angel whose outstretched arm pointed to the temperature at every moment. For convenience the immense air-thermoscope was fastened to the wall of a house on the shady side; it was renowned for its power of showing "the coldest and hottest weather throughout an entire year."

The instrument consisted of a large copper globe joined to a long tube one inch wide, of the same metal; the tube was bent upon itself



Guericke's thermomet'r.

so as to form a very narrow U, in which was placed a certain amount of alcohol. The shorter arm of the U was open at the top; on the liquid within it floated a tiny inverted cup of brass foil to which a cord was attached that passed around a wheel, hung upon the underside of the globe, and carried at the other end a little figure of an angel pointing to the scale on the tube; the tube was concealed from the observer by a wooden case, and the image hung without. A valve at one side of the large copper sphere permitted enough air to be withdrawn by means of the air-pump, to adjust the height of the image, which hung about half way up the tube. On the fifteen-foot scale were the words: "Magnum frigus, aer frigidus, aer subfrigidus, aer temperatus, aer subcalidus, aer calidus, magnus calor;" and the large sphere above the tube was inscribed "Mobile perpetuum."

De Guericke constructed a barometer on similar lines, and gave it the legend "Semper vivum;" he described it in a letter to G. Schott, dated 30 December, 1661.

Still more remarkable was the self-registering meteorological apparatus devised by the great German physicist; it recorded every hour the change in temperature, direction of the wind, the rainfall, and amount of snow or hail. Monconys describes this briefly, with a diagram showing the arrangement, in his Journal des Voyages (Vol. III, 1663).

The differential thermometer was invented by Gaspar Schott, as early as 1657 (Mechan. hydraul-pneumat. II, 231), and afterwards improved by Joh. Christ. Sturm, Professor in Altorf, Bavaria, in 1676. It was a U-tube with arms of uneven length, both tubes being closed; Sturm explained its action quite correctly.

In the latter part of the seventeenth century references in scientific literature to the construction and use of the ordinary thermoscopes multiplied; Le Febure in his admirable treatise on chemistry (1669), mentions the thermometer as a well-known instrument, and Gabriel Clauder in the "Miscellanea curiosa Acad. nat. curiosa" (Dec. 2, Anno 6, p. 351, 1687), describes a "thermoscopium noviter inventum" adapted to immersion in liquids.

There was published at Amsterdam, in 1688, an illustrated work entirely devoted to barometers, thermometers, and hygrometers, written by Dalencé, who concealed his name under the initial D——. I have already referred to this interesting book in connection with the Drebbel myth, but it deserves emphasizing, for it contains an imperfect summary of thermometrical knowledge up to that date; to avoid repetition, however, I shall only notice items not previously given here.

Dalencé describes the Italian thermoscope as having a bulb the size of a pigeon egg and a tube as big as a quill pen; he suggests the use of a mixture of three parts of water with one of aqua fortis to prevent the liquid freezing, and a flattened bulb to permit heat, or cold, more readily to penetrate the centre of the liquid. He proposed, also, that two points should be marked on the scale, the freezing-point of water, to be marked "cold," and the melting-point of butter; the space between them to be divided equally and the centre to be marked "temperate." Then each space above and below "temperate" to be divided into ten equal degrees, four additional degrees to be placed above the melting-point of butter and four below the freezing-point of water, making a scale of thirty degrees in all.

	Dal.	Fahr.
Melting butter . . .	10	86°
Medium	0	
Freezing temperature .	—10	32°

He further proposed another standard scale, the fixed points to be the temperature of a cellar and of ice, the space between to be divided into fifteen degrees; and he added: "all thermometers made by the latter method are comparable." To make instruments easy of transportation, and for fancy, the stems were bent into circular, oval, spiral, triangular, and stellate shapes, and Dalencé gives figures of each. He also described the floating glass bulbs of Kircher, and made them in the shape of turtles to apply to the arms and body of feverish persons. "Some *curieux*," he says, "use mercury in thermometers," but the instrument he writes of was an air-thermoscope and the fluid metal was not employed on account of its property of expansion. Dalencé praised the skill of Sieur Hubin, glass-blower, whose address was Rue St. Martin, Paris, and says his success is due to the fact that "he knows the reasons for that which he does."

The sections in Dalencé's work on the barometer and hygrometer are interesting from the historical point of view, but do not fall within the province of these chapters.

Dalencé seldom gives credit to individuals for their shares in the development of the instruments he describes, and it is difficult to determine how many of the improvements mentioned by him were original with him, probably but few.

Mention may be here made of a complicated thermometer constructed by the expert Parisian glass-blower Hubin, although it was not described in print until 1725 (Reyher, Pneumatica). Two bulbed tubes were united at a reservoir, and bent in the shape of an U; both tubes were closed so that the apparatus was independent of air-pressure. The shorter arm of the U was filled with mercury up to the centre of the reservoir, the longer arm half filled with water, the remaining half, including the large bulb, containing air. When the air in the bulb expanded, it pressed upon the column of water which in turn forced the mercury up the shorter and wider tube. Hubin claimed for this instrument greater delicacy than the Florentine in the proportion of 216 to 4, as determined by experiment.

The question, who first used quicksilver as the dilating liquid in thermometers, is apparently a simple one, to be easily answered, but like many other questions of priority in the history of the thermometer, many claims have been advanced and the problem requires examination; no less than ten names are mentioned by different authorities as inventors of mercury thermometers. Thermometers *containing* mercury were indeed made at an early date, but the liquid metal was only an accessory to the air-thermoscope and was not used as a heat-measurer.

Athanasius Kircher, in 1643, mentions a thermoscope containing mercury, but does not describe the function of the liquid metal. The Accademia del Cimento, as related in the diary of the society, made mercury thermometers in 1657, compared them with water-thermometers of the same size, and observed that the former fell and rose more quickly than the latter when affected by changes of temperature, although the total amount was less; but this important fact lay dormant and unused.

Mercury thermometers were also known in Paris; Ismael Boulliau is said to have made them in 1659; and a letter dated 28th May, 1684, written in Paris to the Royal Society, London, by Mr. Musgrave, describes one three inches long and five lines in diameter, that was used for taking the temperature of fever patients.

Christian Huyghens, in 1665, and Dalencé, in 1668, are also credited with the invention of mercury thermometers. In the same year that Dalencé's book appeared, Edmund Halley, the eminent English mathematician and astronomer, was studying experimentally the relative expansion of water, alcohol and mercury, and he stated that mercury would make a good thermometrical liquid if its coefficient of expansion was greater; he did not actually recommend the liquid metal, although he perceived that its expansion was large enough to influence the readings of the barometer. He observed that mercury heated in boiling water ceased to expand on long continuing the operation, and according to Momber he proposed taking the boiling-point of water as a fixed point, but Poggendorff says he made no application of this fact to thermometry. Halley thought that "spirit of wine" lost part of its expansive force by long keeping, yet he proposed the boiling-point of alcohol as a limit to thermometrical scales. The English scientist felt the need of a reliable thermometer scale and expressed himself in somewhat the same way as his countryman Boyle had done, fourteen years before: "I cannot learn that any thermometer of either sort was ever made or adjusted so as it might be concluded what the degrees or divisions of the said instrument did mean; neither were any thermometers ever otherwise graduated but by standards kept by each particular workman without any agreement or reference to one another. So that whenever observations of a thermometer are made by any curious person to signify the degree of heat in the air or other thing they cannot be understood, unless by those who have by them thermometers of the same make and adjustment."

Halley regarded the freezing-points of aniseed oil, and of water, as unreliable, and preferred as a starting point the temperature of a deep cellar, the constancy of which had been demonstrated by De la Hire in the crypt of the Paris observatory.

Christian Wolf, of Halle, and Olof Römer, of Copenhagen, both in 1709, are also named as the first to use mercury as a heat measuring liquid, but in spite of these many claimants the fact remains that Fahrenheit, in 1714, was incontestably the first to construct mercury thermometers having reliable scales. But this anticipates.

The need of a standard scale, easily made and based on constant phenomena that can be reproduced at will, was felt by all who used thermometers, and an important practical proposal to secure this desideratum was made in 1694 by Carlo Renaldini, a former member of the Accademia del Cimento, and professor of mathematics in Padua. At that date, and in the eightieth year of his age, he published a work on natural philosophy, in which he suggested taking the melting-point of ice and the boiling-point of water for two fixed points of thermometer scales, and dividing the space between them into twelve equal parts. This truly admirable proposition was not appreciated by his contemporaries who did not wholly believe in the constancy of these temperatures, and it was forgotten by succeeding philosophers, thus delaying greatly accurate observations of temperature.

Dalencé had anticipated Renaldini in adopting the principle of the subdivision of the interval between two determinable points, but the phenomena chosen by the Frenchman were not so reliable as those proposed by the Italian, which were afterwards adopted by Celsius.

Renaldini devised another method for graduating thermometers; he plunged the thermometer to be graduated first in mashed ice, then in a mixture of eleven parts cold water plus one of boiling water, and successively in mixtures of ten cold plus two boiling, nine cold plus three boiling, eight cold plus four boiling, and lastly in boiling water itself, marking on the scale the position of the expanding fluid at each immersion. This sounds plausible, but was shown by Wolff to be deceptive and unreliable.

Sir Isaac Newton was one of those who attacked the thermometrical problem of the age, but the scale proposed by this great genius was by no means satisfactory; he rejected alcohol as the dilating liquid and preferred "lintseed" oil; for fixed points in the scale he chose the temperature of melting snow and of the human body, dividing the interval into twelve equal parts. In his paper "Scala graduum," published anonymously in the *Philosophical Transactions*, May, 1701, Newton gave his method of graduation; he assumed that when the instrument was placed in melting snow the linseed oil occupied 10,000 parts, and found that the same oil at the temperature of the human body, which he called one degree of heat, occupied a space of 10,256 parts; in water boiling violently 10,725 parts, and in melted tin beginning to cool 11,516 parts; from this he computed the degrees of heat corresponding to the phenomena, calling the heat of the human body 12, he found for boiling water 34, and melting tin 72. His thermometer was three feet long and had a bulb two inches in diameter.

Newton also made an experiment with a thick piece of iron as a pyrometer; he heated it red hot and "put it in a cold place where the wind blew uniformly," then he placed on the bar particles of various metals and other fusible bodies and noted the *times* of cooling, until all the particles having lost their fluidity grew cold, and the heat of the iron was equal to that of the human body. Then by assuming that the excesses of the heats of the iron and of the solidified substances, above the heat of the atmosphere, were in geometrical progression when the times were in arithmetical progression, all the heats were obtained. From this experiment and computation Newton drew up the following scale of degrees of heat.

NEWTON'S TABLE.

Degrees of heat.	Equal parts of heat.	Phenomena.
0	0	heat of the winter air when water begins to freeze.
1	12	greatest heat of the surface of the human body.
2	24	heat of melting wax.
2.5	34	heat of water boiling vehemently.
3	48	lowest heat at which equal parts of tin and bismuth melt.
4	96	lowest heat at which lead melts.
5	192	heat of a small coal fire not urged by bellows.

Biot, commenting on Newton's paper, notes that it contains three important discoveries: (1) a method of making thermometers comparable by determining the extreme terms of their graduation from the phenomena of constant temperature; (2) the determination of the law of cooling in solid bodies at moderate temperatures; (3) observation of the constancy of temperature in fusion and ebullition.

From Newton's note-books it appears that he was occupied with these studies in March, 1692–3, although they were not made public until 1701.

Newton made no use of the boiling-point of water in constructing his scale of temperatures, as he considered it variable; he recorded that water begins to boil at 33° of his scale, and boils vehemently at 34° to 34½°. We now know that such fluctuations depend upon the position of the thermometer (which must not be immersed in the liquid), on the pressure of the atmosphere, on the chemical purity of the water, and on the shape of the vessel holding it, so it is not surprising that doubts existed as to the constancy of the phenomenon. Mariotte had laid the foundations of hypsometry, but the experimental proofs were not secured until Le Monnier tested the matter in the Pyrenees in 1739.

In the same year that Newton published his researches, Étienne François Geoffroy described an open air-thermoscope nearly identical with that of Athanasius Kircher, made in the year 1643, and to which the French savant made no allusion. (*Phil. Trans.*, 1701, p. 951.)

IV. FAHRENHEIT AND THE FIRST RELIABLE THERMOMETERS.

The eminent French physicist, Guillaume Amontons, lost his hearing when a schoolboy, and like the philosopher of old who destroyed his eyesight for fear visual impressions should disturb his speculations, the Frenchman declined surgical and medical assistance lest the admission of common noises to his brain should interfere with his profound studies in mathematics and mechanics. He became skilled in surveying, able in architecture and distinguished in pure mathematics, and he made important improvements in the hygrometer, the barometer, and the thermometer.

Amontons constructed the first veritable air-thermometer which was not at the same time a barometer; it consisted of a narrow glass tube four feet long, open above, ending below in a large bulb connected by a U-shaped bend; in this bulb air was confined by a column of mercury so adjusted that when the apparatus was immersed in boiling water, the barometer standing at 28 inches, the mercury in the tube stood 45 inches above the level in the bulb, thus making the pressure of the heated air 73 inches. The tube was graduated from 73 inches down in inches and lines (*pouces* and *lignes*), so that on this scale 51.5 inches were equal to 0° C., and 73 inches to 100° C. Readings were corrected by a barometer. This instrument registered the changes in the elastic force of air produced by heat, and was styled by Amontons the "universal thermometer;" but its great length, the difficulty of transporting it, and the inaccuracy due to friction of mercury in the glass tube, prevented it from being adopted.

Amontons is often credited, especially by French authors, with the discovery that the boiling-point of water is constant under like conditions as respects pressure, etc., but this cannot be sustained for it is certain that Renaldini anticipated him in proposing the boiling-point of water as a fixed point, and that Boyle and Papin demonstrated the influence of pressure long before.

The French physicist constructed a mercury thermometer provided with a double scale ascending from 49 to 59 and descending from 14 to 24; in this were the following correspondences: 59° = solidification of tallow; 54° = cellars of the observatory, Paris; 52° = freezing of water. This instrument had no advantages over those in use.

Commenting on the experiments of Sir Isaac Newton with the iron pyrometer, Amontons devised similar ones. Assuming that the temperature increased in arithmetical progression throughout a rod of iron 59 inches long, he obtained the following results.

TEMPERATURES OBTAINED WITH AMONTON'S PYROMETER.

Thin glass melted at	4 pouces 4 lignes.
Lead melted at	8 pouces 6 lignes.
Gunpowder ignited at	8 pouces 6 lignes.
Tin melted at	11 pouces
Alloy of 3 tin and 2 lead melted at	12 pouces
Water boiled at	22 pouces
White wax melted at	30 pouces 8 lignes.
Tallow melted at	39 pouces
Butter melted at	42 pouces

In his paper published in the "Mémoirs de Paris" (1703, p. 50) Amontons makes the oracular statement "heat is the soul of nature, and it is very important for physicists to be able to measure it accurately."

Fourteen years later, Jakob Hermann, a mathematical physicist of Basle, seeking to make thermometrical readings independent of corrections for barometric pressure, proposed to close the tubes of Amontons' air thermometers by fusing the upper ends; this form of instrument he described in a work entitled: "Phoronomia," published at Amsterdam in 1716. This instrument showed directly the elasticity of the confined air, and thereby the temperature, a correction being made for the temperature of the column of mercury.

Frequent allusions to the thermometer of Philippe de la Hire are met with in works on meteorology, and his instrument was famous not because of its novel construction, but owing to the long series of observations conducted with it and published in the Memoirs of the Academy of Sciences, beginning with the year 1670. It was a Florentine thermometer having a scale the value of which has never been accurately determined; La Hire considered it sufficient to state that it had two fixed points, the temperature of a deep cellar in the observatory (48°) and that of the air in an open room when it was freezing in the vicinity.

Amontons sought to compare his standard thermometer with that of La Hire, but could not obtain permission from the authorities to place his instrument alongside of it in the observatory; after his death a superficial comparison was made. Lambert says the zero of La Hire's scale was the temperature of a mixture of snow and salt, and the 100 degrees was the temperature of melted tallow about to solidify.

It is, of course, inexpedient to attempt to chronicle in this volume every printed note on the thermometer, many of which did not bring their authors much fame, and did little to advance the instrument to perfection. But brief reference may be made to a "Dissertation" by Gabriel Philippe de la Hire, (Mémoires Acad. Science, Paris, 1706, p. 432), (son of Philippe just named) in which he mentions an instrument invented by Nugent in 1706, resembling that of Huyghens, and to a short article on the "Construction of Thermometers," by Elias Cammerarius in 1712 (Ephem. Acad. Nat. Curiosa, C. 1 and 2, p. 370), before we consider the eminent services to thermometry rendered by Fahrenheit.

In the year 1714, Christian Freiherr von Wolf, Chancellor of the University of Halle, and professor of mathematics and philosophy in the same, received a visit from Fahrenheit, a maker of philosophical apparatus in Amsterdam, who presented him with two thermometers made by himself, which agreed so perfectly in registering temperatures that the learned professor was amazed; he considered the unusual phenomenon so remarkable that he wrote a paper for the Acta Eruditorum in the same year, ascribing the concordance to certain singular properties of the alcohol. Nothing can illustrate more cogently the imperfections of the best instruments then in scientific hands, and the character of those in ordinary use can be imagined; nothing can better demonstrate the immense advance made by Fahrenheit, and even those who deprecate the wide use of his illogical scale must pay tribute to the value of his services in developing reliable thermometers.

Daniel Gabriel Fahrenheit was born at Danzig, 24th May, 1686, the son of a well-to-do merchant. After receiving private instruction at home he attended the gymnasium, but when fifteen years old he had the misfortune to lose both his parents in one day (14 Aug., 1701), and was then sent to Amsterdam to enter a business house. There he completed his apprenticeship of four years, but forsook commerce in order to follow his inclination to study physical science and to travel; he became interested in meteorology and acquired great skill in constructing thermometers. In 1714 he visited glass-works in Berlin and Dresden to supervise the manufacture of the tubes for his instruments, and on this journey he called on Professor von Wolf in Halle, as stated.

Returning to Amsterdam he established himself as a maker of philosophical instruments; at that period three distinguished men of science honored Holland, Dr. Hermann Boerhaave, professor of medicine and chemistry in Leyden, Pieter van Musschenbroek, professor of mathematics and physics in Utrecht, and Willem Jacob van 'sGravesande, astronomer and mathematician at the Hague, and these refer in their writings to Fahrenheit and his thermometers. When he visited England some time prior to 1724, he was well received and honored by election to membership in the Royal Society. Fahrenheit died unmarried in the land of his adoption 16th September, 1736, at the age of fifty years; he was buried in the Klosterkirche in the Hague.

Fahrenheit's practical work in thermometry began as early as 1706; at first he used alcohol only, but afterwards became famous for his mercury thermometers. In 1709 he sent his instruments to distant places, Iceland and Lapland, and took them in person to Sweden and

Denmark. For eighteen years Fahrenheit kept secret his method of manufacture for commercial reasons, but between 1724 and 1726 he published five brief papers in the *Philosophical Transactions.* Many of the experiments date, however, from 1721.

In the first of these he gives the specific gravity and boiling-points of five liquids, alcohol, rain-water, nitric acid, potash-lye, and sulfuric acid, taken at 48° of his scale; this temperature, he explains, is half-way between that of the intense cold obtained by a mixture of water, ice and sal-ammoniac, or common salt, and that of the blood of man.

The second paper, on the freezing of water in vacuo, contains the interesting observation that water can remain liquid below its freezing-point; incidentally Fahrenheit describes his thermometer.

The third paper contains the specific gravity of 29 substances, solid and liquid, the determination having been made with the balance and with the new hydrometer described in paper No. 4. This instrument was the first hydrometer of constant volume; it had a pan for carrying weights like Nicholson's (which was patterned after it), and was the first that could be used for all liquids.

In the fifth paper Fahrenheit describes his invention of the thermo-barometer, based on the fact that the boiling-boint of water is influenced by barometric pressure. Boyle had observed the lowering of the boiling-point under the receiver of the air-pump, but Fahrenheit was the first to discover the principles of hypsometry.

Fahrenheit's publications are few in number and very brief, but they show him to have been an original thinker, and his great mechanical skill in working glass enabled him to carry out his designs. His account of the thermometer is of so great interest that I give it entire.

"The thermometers constructed by me are chiefly of two kinds, one is filled with alcohol and the other with mercury. Their length varies with the use to which they are put, but all the instruments have this in common: the degrees of their scales agree with one another and their variations are between fixed limits. The scales of thermometers used for meteorological observations begin below with 0° and go to 96°. The division of the scale depends upon three fixed points which are obtained in the following manner: The first point below, at the beginning of the scale, was found by a mixture of ice, water and sal-ammoniac, or also sea-salt; when a thermometer is put in such a mixture the liquid falls until it reaches a point designated as zero. This experiment succeeds better in winter than in summer. The second point is obtained when water and ice are mixed without the salts named; when a thermometer is put into this mixture the liquid stands at 32°, and this I call the commencement of freezing, for still water becomes coated with a film of ice in winter when the liquid in the thermometer reaches that point. The third point is at 96°; the alcohol expands to this height when the thermometer is placed in the mouth, or the arm-pit, of a healthy man and held there until it acquires the temperature of the body. If, however, the temperature of a person suffering from fever, or some other disease, is to be taken another thermometer must be used having a scale lengthened to 128° or 132°. Whether these degrees are high enough for the hottest fevers I have not examined; I do not think, however, that the degrees named will ever be exceeded in any fever.

"The scales of such thermometers as are

used for determining the boiling-points of liquids begin also at 0° and run up to 600°, for at about this temperature mercury begins to boil. To increase the sensitiveness of thermometers they are made with cylinders instead of spheres, so that a larger surface will be more quickly affected."

Fahrenheit then gives a full account of his method of filling thermometers with liquids, a practical feature not necessary to detail in this place. The fever thermometers were known as "Pyranthropometers."

While these scanty records are all given us by Fahrenheit himself, other details are furnished by contemporary writers; Christian von Wolf describes the instruments given him by Fahrenheit thus:

The two thermometers had cylinders in place of spheres and were filled with colored alcohol. The cylinder of one was one and three-eighths inches long (12 inches to a Paris foot), thirteen sixty-fourths inch in diameter, and the lower portion ended in a sphere; the tube was six and eleven-sixteenths inches long. The scale was six and seven-sixteenths inches long and had 26 degrees, each of which was divided into four. The second degree on the cylinder was marked "greatest cold" (0° F.), and from this to the upper end were 24 degrees, some bearing special names; the fourth was "very cold," the eighth "cold," the twelfth "moderate," the sixteenth "warm," the twentieth "very hot," and the twenty-fourth "unbearable heat." The second tube of Wolf differed little in size. Wolf tested the two instruments and found the slight difference between them of one-four hundred and sixteenth of the entire scale.

Another friendly contemporary of Fahrenheit, Dr. Hermann Boerhaave, has recorded in his "Elements of Chemistry" some particulars of the celebrated thermometers. Boerhaave, writing in 1731, ascribes the invention of the thermometer to Drebbel, cites Amontons, Mariotte, and others, and gives an account of a noteworthy experiment made by Fahrenheit, who poured spirit of nitre on ice and got a temperature of —29° F., using an instrument graduated to —79°. Boerhaave then describes "an elegant thermometer made at his request by the skilled artist Daniel Gabriel Fahrenheit" thus: "The lower cylinder of this instrument contains 11,124 parts of mercury, which in the utmost cold observed in Iceland reached to the mark 0 from whence the further degrees of heat are computed upwards. Now if this be immersed in a vessel of water gradually heated, the mercury will be found to ascend continually till the water comes to boil, at 212° or more; so that setting aside the dilatation of the glass it now possesses 11,336 spaces of which in the greatest cold it possessed 11,124, so that by this difference of heat the bulk is dilated to $\frac{1}{52 - \frac{25}{53}}$.”

In another passage, Boerhaave relates that on comparing two of Fahrenheit's thermometers, one of alcohol and one of mercury, he found a slight discrepancy and reported it to the maker, who “ingeniously owned the failing, but did not then see the cause of it, but revolving it in his own mind he at length discovered that the very glass made in Bohemia, England, and Holland expands more or less easily by the same degree of heat,” and Fahrenheit suggested that the two instruments ought to be made of one kind of glass. Thereupon the doctor adds this comment: “How circumspect does nature require us to be in order to discover truth in physical matters, and how often are we deceived by following a general rule.”

Fahrenheit made his thermometers with different scales at different times, commonly known as the large, medium, and small scales, their correspondence and value being shown in the table.

I. Large.	II. Medium.	III. Small.	(Centigrade.)
90	24	96	35.5
0	12	48	8.8
—90	0	0	—17.8

In No. I the 0° was placed at "temperate" as in the Florentine scale; in No. II each space was divided into four equal parts, and these smaller divisions were afterwards taken as degrees, thus forming scale No. III.

The earliest thermometers were made to indicate temperature up to 96° only; it does not appear that Fahrenheit used the boiling-point of water as a fixed point, although he alludes in his first paper to the fact that Amontons had shown that water boils at a constant temperature. The origin of the numbers 32 for the freezing-point and 212 for the boiling-point of water is obscure, they may have arisen in this way: After Fahrenheit abandoned the Florentine scale —90–0–90, he arbitrarily contrived the scale 0–12–24 taken from the familiar foot measure, but the spaces being too large for accurate readings each was divided into four, and thus arose the scale 0–48–96. When he made thermometers for higher temperatures the scale was merely lengthened by adding more spaces of equal size, and one of the divisions marked 212 accidentally coincided with the level of the liquid at the boiling-point of water; Fahrenheit never had any intention of dividing the interval between his zero and the boiling-point of water into 212 parts.

It is a singular thing, however, that if we adopt the fixed points 32 and 212, the actual temperature of the human body is 98° not 96°; so the Fahrenheit scale now in use is not exactly the original. Moreover the zero of the Florentine thermometer is given by him as equal to 45° F. and by others as 48°.

Uncertainty also exists as to the exact temperature selected by Fahrenheit for his zero; the proportions of ice, water, and salt (or sal-ammoniac) in the mixture he used are unknown. Rüdorff has shown that the temperature obtained by mixing 100 parts of snow and 33 of salt equals —21.3° C., and 100 parts snow with 25 of sal-ammoniac gives —15.4° C., whereas the modern Fahrenheit zero is equal to 17.8° C. Fahrenheit's original mixture must have contained the two salts in proportions now indeterminable.

According to Boerhaave, Fahrenheit's zero coincides with the greatest natural cold observed in Iceland in the winter of 1709, and this is sometimes stated to have been the origin of the lower fixed point in the scale. Surely that winter was remarkably mild in frozen Iceland, for zero is often exceeded in countries not regarded as arctic; yet Boerhaave remarks that "nature never produced a cold beyond zero." The Meteorological Yearbook for Denmark shows that the temperature fell in March 1888, at Stykkisholm, Iceland, to —8.5° F.

There is another element of uncertainty in Fahrenheit's scale. Both Musschenbroek and Boerhaave state that the bulb of Fahrenheit's thermometer contains 11,124 parts of mercury at zero and that when the bulb is placed in melting ice the metal expands 32 of these parts; but Boerhaave, in another place, says the bulb contains 10,872 parts of mercury, and in still a third passage he gives the number of parts as 11,520, which Dr. Martine apprehends is nearer the truth. These vaguely named "parts" depend upon the figures taken for the expansion of mercury; to show their derivation we must bear in mind that the ratio between the capacity of the bulb and of the stem is constant for equal increments of heat.

Let x = the quantity of mercury in the bulb at 32°,
180 = number of degrees between the boiling-point and freezing-point of water,
$\frac{161.7}{10,000}$ = expansion of mercury between these two temperatures,

then: $161.7 : 10,000 = 180 : x$, and $x = 11,124$.

(Fahrenheit's figure 161.7 is, however, erroneous, it should be 181.53.)

A number of Fahrenheit's original thermometers are preserved in European institutions; two are in the physical cabinet, Leyden, one 653 mm. long is graduated from —4° to 600°, the other one is 232 mm. long and has a scale from —4° to 100°. Both are filled with mercury. Comparison with a modern standard thermometer shows that the freezing-point of water in the larger one is 34.2°, and in the smaller 34.1°. The Real Gymnasium of St. Peter, in Danzig, treasures one of Fahrenheit's early thermometers; it is filled with alcohol, measures 110 mm. in length, and has attached in a glass tube a paper scale graduated from

0° to 100°. Above the scale is the inscription: "Cilinder termometron Ferneid."

Fahrenheit was followed almost immediately by a host of imitators, each devising a scale differing from Fahrenheit's and from one another, none of them possessing any special advantage. In 1712 to 1713, Fahrenheit, being in Berlin, communicated his method of constructing thermometers to his teacher of higher mathematics, Prof. Barnsdorf, and the latter made instruments with a scale of his own, the relation being as follows:

Fahrenheit.	Barnsdorf.
96	13
18	11
4.5	0
0	—1

Barnsdorf taught the art to Dr. Lange, professor of mathematics in Halle, and he devised a scale of his own:

Fahrenheit.	Lange.
96	24
52.3	12
48	10.8
6.4	0
0	—1.7

Besides these imitators of Fahrenheit there may be named Christian Kirch, professor of astronomy in Berlin, Chr. Friedr. Ludolff, Sisson, and Bergen, whose scale made 32° Fahrenheit = 6° B., and 212° Fahrenheit = 174° B. Michael Christian Hanow, of Danzig, adopted a scale in which two degrees Fahrenheit equaled one degree H.; having observed in 1740 that the alcohol in a Fahrenheit thermometer fell to ten degrees below zero, he immediately devised a scale in which the zero-point was lowered ten degrees.

These objectionable imitations of Fahrenheit's thermometers brought the genuine ones into evil repute, but the latter outlived their rivals and Fahrenheit's scale is the popular one wherever English is spoken. The weakness of Fahrenheit's scale was the three fixed points somewhat vaguely defined.

V. THERMOMETERS OF RÉAUMUR, CELSIUS, AND OTHERS.

Thermometers for a special and limited use were manufactured about 1727 by John Fowler, Swithin's alley, near the Royal Exchange, London; these were adapted to the cultivation of hot-house plants, being graduated to indicate degrees most "kindly" to given plants. The instruments varied in length from 18 inches to 4 feet, and the stems were marked from freezing-point of water to 90° a temperature equal to that of warm water capable of being endured by the hand held still, certainly a very vague standard but perhaps sufficiently accurate for vegetable life.

The proper temperatures for specified plants were as follows, the degrees being those given by Hales.

HALES' TABLE.

Melon thistles	31
Ananas	29
Piamento	26
Euphorbium	24
Cereus	21
Aloes	19
Indian figs	16
Ficoides	14
Oranges	12
Mistles	9

(*Phil. Trans.*, Apr.-June, 1727.)

These instruments were used by the eminent botanist, Rev. Stephen Hales, who describes them in his "Vegetable Statics," 1727 (p. 61). Dr. Hales remarks that "64 of these degrees is nearly equal to the heat of the blood of animals," which he determined by placing the "ball of the thermometer in the blood of an expiring ox." The "temperate" point was about 18 of these degrees.

Réaumur, who next sought to improve the thermometer, was one of the most popular savants in France; his position in the world of science as well as in that of society, was far more conspicuous than that of the humble artisan Fahrenheit, and his aristocratic station is evidenced by his full name: René Antoine Ferchault, Seigneur de Réaumur, des Angles et de la Bermondière. He early became a member of the French Academy of Sciences, and for more than fifty years assiduously cultivated the sciences; his studies embraced the industrial arts, the physical and the natural sciences, and his publications were very numerous. In the Memoirs of the Academy of Sciences for 1731 he published a long paper entitled: "Rules for the Construction of Thermometers with Comparable Scales," which in its verbosity and prolixity contrasts strongly with Fahrenheit's conciseness.

Réaumur, like so many Frenchmen, completely ignored the thermometrical labors of the German, and rejected quicksilver, owing to its small coefficient of expansion; he sought by means of dilute alcohol to arrange a scale so that a definite change in volume would correspond to a definite rise or fall in temperature.

He adopted a single fixed point, the freezing-point of water, a constant more difficult to determine accurately than the melting-point of ice; he ascertained that alcohol diluted with one-fifth water expanded from 1000 to 1080 volumes between the freezing- and boiling-points of water, and so he took zero for the lower and 80 for the higher temperature, dividing the intervening space into 80 parts.

Réaumur showed much ingenuity in his experimental work, but in his theoretical conclusions he made serious errors; he believed erroneously that he obtained the temperature of boiling water by immersing the unsealed alcohol tube in boiling water, and he ignored the influence of air-pressure, although Fahrenheit's experiments were generally known. For these and other reasons his thermometers were not satisfactory; with bulbs three to four inches in diameter the instruments were too large for standardizing smaller ones, and attempts to transfer Réaumur's scale to mercury thermometers led to confusion. Lambert, writing in 1779, gives for Réaumur three scales: first, that intended by him, second, the so-called Réaumur scale applied to mercury thermometers. and third, the scale actually obtained by the savant, which did not, however, agree with that proposed by him.

Thermometers made after Réaumur's plans were constructed by the Abbé Nollet (1732), by Tobias Mayer, by Boissier de Sauvages, and by Brisson; the latter proposed quite properly to use the melting-point of ice rather than the freezing-point of water as the lower fixed point, and he took the heat of the human body for a second fixed point making it equal to 32½ degrees Brisson.

The Abbé Soumille constructed a thermometer like that of Réaumur, but in four sections; in the first section the temperature of melting ice was placed at the top of the tube, and the tube was graduated downward to —20 at the bottom; the second section began where the first ended, the temperature of melting ice being at the bottom of the tube and the scale extending to +20; the third section ran from 20 to 40 and the fourth to 60. The spaces between degrees were an inch long admitting of fine subdivision. (Hist. Acad. Sci., Paris, 1770, p. 112.)

Réaumur's methods were severely criticized by De Luc in his researches on the modifications of the atmosphere; on the other hand

Lambert makes the caustic remark: "Had De Luc written a work four times as small, he might have said four times as much as he did say."

Shortly after Réaumur's publication Joseph Nicolas de l'Isle, professor of astronomy in St. Petersburg, devised a thermometer on the same principles, but adopted as the point of departure the temperature of boiling water, calling it zero, and adjusting the scale so that the freezing-point of water equaled 150 degrees. This instrument was not much used outside of Russia.

In 1741, Jacques Barthélémi Micheli du Crest, of Switzerland, an army officer, presented many arguments against the scale of Réaumur; he used mercury only for calibrating tubes and rejected it as a thermometrical liquid, owing to the great difficulty of purifying it, preferring alcohol that had stood the gunpowder test. He took as one fixed point the "temperature of the terrestrial globe," as observed in the cellar of the Paris observatory, 84 feet deep, and as the second fixed point the boiling-point of water; the interval he divided into 100 degrees. The degrees in this scale nearly coincide with those of Réaumur. The thermometer of Du Crest was commonly used in northern Switzerland, and only a few years ago aged people often cited air-temperatures in Du Crest degrees.

In 1749 Du Crest was condemned for political reasons to lifelong imprisonment, and during the seventeen years that he spent in the fortress at Aargau he published several papers on meteorology; he died in 1766.

Anders Celsius, professor of astronomy at Upsala, proposed in 1742 a scale with zero at the boiling-point of water (the barometer at 25 inches, 3 lines), and with 100 at the temperature of melting ice. Celsius's scale is sometimes confounded with the French centesimal scale now in use, through neglect to remember the inversion. The change to the modern centigrade was made by two scientists independently, Christin, of Lyons, and Märten Strömer, of Upsala. The Lyons savant worked out the same plan as Celsius independently and published his results in the local papers in 1743. He disregarded the barometric pressure but in other respects his thermometer did not differ from the mercury centigrade thermometer of France; Christin's instrument was known as the thermometer of Lyons.

Seven years later Strömer, a colleague of Celsius, also inverted the scale and his thermometer was used in meteorological observations at Upsala from 1750.

The centesimal division of the scale between the freezing-point and the boiling-point has been claimed for Linnaeus, the eminent Swedish botanist. In 1844, Arago made a communication to the French Academy of Sciences, quoting a private letter of Linnaeus, who wrote that he was the first to construct a thermometer with the centesimal division of the scale between the freezing-point and the boiling-point of water, for use in a green-house. Unfortunately the date of Linnaeus' letter is not given. (*Compte rendu*, **18**, 1063.)

I have now completed the task undertaken, *viz.*, to sketch impartially the history of the evolution of the thermometer from its first beginnings in Italy, through its crude early forms down to the three standards now commonly used in all civilized lands. It is interesting to note: First, that no nation makes popular use of the thermometer designed by its own citizen. The instrument constructed by the German Fahrenheit in the Netherlands is used almost exclusively in English-speaking lands;

that invented by the Frenchman Réaumer finds no credit in France, but is popular in Germany; and that of Celsius, the Swede, modified by Christin, of Lyons, is used chiefly in France, Belgium, and Switzerland.

Secondly, no one of the thermometers now in use has exactly the scale originally devised by the person whose name is attached to it, later and more perfect methods of manufacture having modified the primary form.

The following table of thirty-five thermometer scales has been compiled from many sources, including the tables of Dr. Martine and of Van Swinden.

TABLE OF THIRTY-FIVE THERMOMETER SCALES.

Date.	1641	1641	1670	1688	1701	1702	1706	1709	1714	1709	1713	1715	1715		1717		1727
Name.	Florentine I	Florentine II	Paris	Dalencé (A)	Newton	Amontons (B)	De la Hire (C)	Fahrenheit I	Fahrenheit II	Poleni	Barnsdorf	Lange	Kirch	La Court	Cruquins	Royal Society (D)	Fowler (E)
B. P.	174	81.7	239	. .	34	73	119.4	. .	[212°]	62.9	. .	. .	. .	. .	1510	. .	. .
Blood heat . .	73	37.5	102	. .	12.5	59.2	89	90	96	52.8	13	24	22.7	45	1227	. .	. .
F. P.	18.5	13.5	25	—10	0	51.5	23	—30	32	47.3	. .	. .	7	15	1070	73.3	—35
Zero F	—8	—8.5	11	. .	—5.5	46	3	—90	0	44.5	—1	—1.7	1	1.5	992	85.9	—53
Notes	Air	Air	Air	Air	Linse'd	Air	Air	Alcoh'l	Hg	. .	. .	. .	. .	. .	Air	. .	. .

A Dalencé, melting butter 10 = 86 F.; medium 0 = 59 F.
B Van Swinden gives blood heat = 58.3; F. P. = 52; zero = 49.2
C Van Swinden gives blood heat = 83.1; F. P. = 31.8; zero = 9.25.
D Zero R. S. = 88 Fahr. Authorities differ greatly.
E Zero Fowler = 52 Fahr.

TABLE OF THERMOMETER SCALES—(*Continued*).

Date.	1727	1729	1730	1731	1733	1739	1740		1742	1743	1747	1750		1758	1761		1772	
Name.	Hales (F)	Richter	Réaumur	Edinburgh (G)	De l'Isle	Hanow	Du Crest	Ludolf	Celsius	Christin	Miles	Strömer	Bergen	Sulzer	Brisson	Sue de Lyon	De Luc	Murray (H)
B. P. . . .	163	. .	80	47	0	. .	100	. .	0	100	. .	100	174	156	. .	. .	. .	347
Blood heat. .	52	47.2	30.8	22.2	96.5	90.1	22.8	89	64.3	35.5	64	35.5	. .	56	30.9	35.6	28.5	. .
F. P. . . .	0	18	0	8.2	150	30	10.4	32	100	0	0	0	6	0	0	0	0	99
Zero Fahr	—24.2	3.4	—14.2	2.04	176.2	0	—24.9	3.5	117	—17.7	—32	—17.7	. .	—29	—15	—17.5	14	. .
Notes . .	. .	. .	Alcoh'l	. .	. .	. .	. .	. .	Hg	. .	. .	. .	. .	. .	Hg	. .	Hg	. .

F Van Swinden gives blood heat = 54.

G Van Swinden gives zero = 1.29.

H Zero at F. P. of mercury.

CHRONOLOGICAL EPITOME.

1595	Open air-thermoscope invented by Galileo.
1611	Sanctorius applies Galileo's instrument to the diagnosis of fevers.
1611	Telioux' thermoscope.
1617	The word "thermoscope" used by Giuseppe Bianconi.
1624	The word "thermometer" used by Leurechon.
1632	Water-thermoscope invented by Jean Rey.
1641	Sealed alcohol thermometers of Ferdinand II.
1651	Caspar Ens originates the Drebbel myth.
1643	Kircher's thermoscopes.
1657	Differential thermometer of Caspar Schott.
1660	Giant thermometer of De Guericke, and self-registering thermometer.
1661	Fabri makes a scale by dividing the interval between the temperature of snow and of mid-summer heat.
1664	Freezing-point of water taken as a fixed point on scale by Robert Hooke.
1665	Boyle uses aniseed oil to get fixed point on scale.
1667	Florentine thermometers described in the "Saggi."
1670	Paris thermometer.
1688	Dalencé publishes his "Traitté" and proposes divers scales.

1694	Renaldini proposes freezing-point and boiling-point of water as fixed points in scale.
1701	Sir Isaac Newton's linseed oil thermometer.
1702	Amontons' researches.
1709	Fahrenheit's alcohol thermometers.
1714	Fahrenheit's mercury thermometers.
1727	Fowler's thermometers.
1730	Réaumur's thermometers.
1733	De Lisle's thermometer.
1740	Scale of Du Crest.
1742	Scale of Celsius.
1743	Christin reverses the scale of Celsius and thereby establishes the "Centigrade" scale.

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