

# THE RELATION OF RÖMER AND FAHRENHEIT TO THE THERMOMETER.

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(Ole, or Olaf, or Olaus, Römer was born at Aarhus, Denmark, September 25, 1644; died at Copenhagen, September 19, 1710. In 1662, he became pupil and amanuensis of E. Bartholin, in Copenhagen, who employed him in classifying the manuscripts of Tycho Brahe. In 1671, he helped J. Picard redetermine the geographical position of Tycho's observatory, Uraniborg. In 1671 or 1672, he went with Picard to Paris; there he became mathematical tutor of the Dauphin and member of the Academy of Sciences, and was occupied with observations in the royal observatory and the king's hydraulic works at Versailles and Marly. In 1674, probably before Desargues and La Hire, he invented the epicycloid and indicated its applications to gear teeth. September 22, 1675, he read his paper on the velocity of light as deduced from observations of the eclipses of Jupiter's first satellite. About the same time he was interested in the design and construction of planetaria. In 1681, he returned to Copenhagen, as royal mathematician and professor of astronomy in the university. He also became mayor, chief of police and privy counselor. On his advice, Denmark adopted the Gregorian calendar.

He invented the transit and prime vertical instruments and the meridian circle, and used altazimuth circles and the equatorial mounting for telescopes. His realization of the importance of clock rate in meridian work led to an interest in expansion and contraction and a fundamental improvement in thermometers, as shown below. His observations and papers perished in the Copenhagen fire of 1728, with the exception of three night's work, preserved by Horrebow, 1735, and discussed by Galle, 1845, the *Adversaria*, mentioned below, and, of course, a few published in the proceedings of the Berlin and Paris academies. At the time of his death he was engaged in attempts to discover stellar parallax, which would inevitably have led him to the discovery of aberration, for reduction of his work has shown it to be of almost modern precision.

Accessible works are, R. Grant, *Hist. of Phys. Astr.*, p. 461; Dobereck, *Nature*, 17, p. 105, 1877-78; See, *Pop. Astron.*, No. 105, May, 1903. A portrait of Römer is to be found in LaCour and Appel, Vol. I.

I find slight discrepancies among the various reference works as to dates and facts of Römer's life; Dobereck's article is very full.

Kirstine Meyer, née Bjerrum, has written in Danish a book on *The Development of the Temperature Concept in the Course of the Ages*, published, 1913, in the series, *Die Wissenschaft*. Her account of Römer's part in the development of the thermometer is here translated from this German edition. It appeared first in *Archiv für die Geschichte der Naturwissenschaften und der Technik*, 2, p. 323-349, 1910.—W. J. F.)

From occasional expressions in the scientific literature of the eighteenth century, on which I came accidentally, I inferred that probably Ole Römer had busied himself with the construction of thermometers, and that there had been a relation between him and Fahrenheit. I will later come back to these expressions. They led me to search in the libraries and archives at Copenhagen for works by Römer, and only at last in the University Library; for I had to assume that the papers of Römer in possession of this library had been destroyed by the conflagration of 1728. Yet there I found what I sought, namely, Römer's *Adversaria*, in manuscript, in a volume of miscellanies.<sup>1</sup>

A note on the last page tells how the book came into the possession of the library, and that it escaped the fire through being then in the possession of Römer's widow, remarried to Th. Bartholin. She gave it to the library in 1739. This note says:

"Da mein erster Gatte Olaus Römer Sel. diese cahiers in Pergament hat heften lassen, möchte ich annehmen, dass er sie selbst als von einiger Importance erachtete, weshalb ich dieses Volumen in der Bibliotheca Academica geborgen wissen möchte unter anderen Manuscripten, damit jemand darin, wie zu vermuten, etwas Nützliches darin finden könnte. E. M. Bartholin, Witwe von Th. Bartholin Sel., in octobre 1739."

This book contains a whole section on the thermometer and, besides, a few isolated remarks on temperature measurement. Römer's form of the thermometer seems to me to be of great interest; he is apparently the first to construct the thermometer with two fixed points, namely, the temperatures of melting snow (*nix sine gelu et calore*) and the boiling point of water, and with a division of the tube into equal volumes.<sup>2</sup> This happened in 1702, partly according to Römer's own notes, partly according to Horrebow's. In *Adversaria*, p. 131 b., there is a reference to Amonton's comparison<sup>3</sup> between his own and Newton's<sup>4</sup> statements of equal temperatures; Römer makes a brief extract from the comparison tables, and adds:

"The observation of the incipient freezing and of the boiling of water seems to me in the highest degree adapted for application in the construction and graduation of a universal thermometer, as the former point is sufficiently well fixed, and the latter, contrary to my earlier view, deserves confidence; for, according to the concurrent observations and reliable assurances of the French, boiling water, once the boiling has begun, cannot increase its temperature."

In 1703, then, Römer seems to have been clear about the principle. Horrebow has made marginal notes at various places in the *Adversaria*, from which it appears that Römer made his thermometers about 1702. He writes,<sup>5</sup>

<sup>1</sup>This *Adversaria*, written mostly in Latin, has been published by the Royal Danish Scientific Society on the occasion of the two-hundredth anniversary of Römer's death, under the editorship of cand. mag. Thyra Eibe and Dr. phil. Kirstine Meyer.

<sup>2</sup>On this see translator's note at end.

<sup>3</sup>Mem. de l'Académie Roy. des Sciences, 1703, p. 100.

<sup>4</sup>Roy. Soc. Phil. Trans., 22, p. 824, 1700-1701. On this scale the ice point is zero, body heat 12, water boiling violently 34; this makes body heat 35.3 C.; cf. 36.9, actual mean. I do not know that Newton ever attempted to construct a thermometer giving these readings, and I think the original shows that he did not consider the boiling point of water a constant, in spite of the observations of Halley and others.—W. J. F.

<sup>5</sup>*Adversaria*, p. 118 b.

"1741, on April 10, I asked Römer's widow when he had made the five thermometers.<sup>6</sup> She answered, they had been made in her presence; she could not, however, recollect any contemporaneous event, through which the date could be determined; but at that time Römer could not get out, owing to a broken leg. Consequently it was before 1703, the year in which, in June, I came to Römer's observatory, for Rumohr, John and other assistants were telling that he had been dangerously ill with wound fever after a broken leg.

"On 17 April, Römer's widow came to me and said, now she knew certainly that these thermometers had been made in 1702."

The section of the *Adversaria* which deals with thermometers, etc., consists of eleven folio pages. The first heading runs, "On the calibration of glass tubes for thermometers." A solution is given of the problem, so to divide thermometers with various sized bulbs and bores, that the divisions shall agree; i. e., so that the volume of ten divisions shall everywhere have the same ratio to the volume of the bulb. He finds the diameter of the tube by means of a quicksilver drop; this he puts into the tube and measures its length, then he weighs it and calculates its volume, assuming that a cubic foot of quicksilver weighs 837 pounds. From this we see that he takes the specific gravity of quicksilver 13.5, as in the system of measures used by him a cubic foot of water weighs 62 pounds.

After he has determined the length and volume of the drop, he calculates its diameter, and so the diameter of the tube, at the region where the drop lies. That Römer is interested in this connection with the problem probably depends on this: that on several sides, as, e. g., by R. Hooke, it had been proposed to make mutually agreeing thermometers on the following principle: one fixed point, and a division of the tube into equal volumes, which should in all thermometers be in the same ratio to the bulb volume.

After solving this problem he gives a suitable formula, and adds that this really has nothing to do with his investigations, which were for determining the irregularities of the tube bores, usually conical or of irregular form.

"I investigate their form by means of a quicksilver drop before the bulb is blown on. In the tube previously mentioned I have found a sufficiently regular part, so that at the middle a

<sup>6</sup>It had previously been mentioned that Horrebow had used these.

drop of quicksilver had length 7 1-2, at the wide end 8, at the narrow end 7 (arbitrary units). Between these points there were ten inches. We can consider this space a truncated cone. In this, unequal thermometer graduations must be made; i. e., longer toward the narrow end, shorter toward the wider cross-section."

The following pages deal generally with the division of conical spaces into equal volumes. Römer develops for this the necessary formulas, and explains them with numerical examples. So he finds a method suitable for dividing a conical tube into equal volumes. Then he passes to his principal problem, for whose sake the preceding developments were entered on, "To construct an original (standard) thermometer."

1. With a quicksilver drop it is found whether the tube is of regular internal form, cylindrical or conical, and, indeed, before the bulb is blown on. Irregular forms are thrown away, cylindrical are used without more ado. With conical ones we have to deal thus:

2. From the middle toward the ends we determine the lengths of quicksilver drops.

3. When the tube is thus divided into two equal parts, then each of these is again divided into two equal parts, so that we now have four equal parts.

4. When the thermometer is completed, filled and sealed, we fix with snow or pounded ice the point 7 1-2, and by boiling, the point 60.

After this are notes, written and signed by Horrebow:

"The distance from the limit of the snow to boiling (melting point to boiling point) Römer divides into seven equal parts, of which the one below the snow limit serves him for observations of greater cold. When he afterward noted that the thermometer sank below zero, he began to number downwards, from zero on with the sign —.

"1739, Römer's widow sent me five glasses for thermometers, which Römer himself had filled according to his rules described above, and had marked with two points. The spirits of wine in them is pretty pale, although Römer had colored it in the usual way. I asked Römer's widow if she knew whether Römer, after I left his observatories, had made any changes in his thermometer. She said that she did not know, but gave me Römer's 'Vade Mecum', in which I found a loose leaf, that is here pasted in after the next leaf. On this sheet I see that Römer had put in the graduation mark for snow; now, insofar as we know, the spirits of wine never sink below zero in Copenhagen, and it is noted that on 7 January, 1709, the spirits sank only to 7 9-10."

This loose sheet mentioned by Horrebow contains a table for

the daily temperatures from 26 December, 1708, to 1 April, 1709.<sup>7</sup>

(Here follow a description and a partial figure of Römer's graphical record of temperature, one of the earliest temperature records which can be translated into modern scales with approximate accuracy. For these I make reference to the original. —W. J. F.)

Certain places in the *Adversaria* lead one to suspect that Römer had considered dividing the tube into equal lengths and making for each thermometer a table of the deviations shown between the readings of such a thermometer and one divided in equal volumes.

To sum up: We arrive at the conclusion mentioned above, the thermometer graduation rests on two fixed points, the melting point of snow, usually called the "freezing point," and the boiling point of water, and then on the determination of degree lengths by division of the tube between the two fixed points into equal volumes, in doing which account is taken of the cylindrical or other form of the tube. The size of a degree is such that between freezing and boiling points there are 52 1-2 degrees of equal volume. If the tube is cylindrical, this distance is divided into 52 1-2 equal lengths, and 7 1-2 such are marked off below the freezing point, giving the zero point; if the tube is not cylindrical, but conical, the graduation from freezing point to boiling point is carried out according to Römer's previously given method for the graduation of conical tubes; the zero point is so located that the volume from zero to freezing point is 1-7 of that from freezing point to boiling point.

Römer's thermometers were still in existence up to 1748,<sup>8</sup> for in his *Elementa Philosophiae Naturalis*, p. 144, Horrebow says that he had got from Römer's widow, who still owned them, five thermometers. In the *Adversaria* Horrebow tells further that he had tested them, and remarks,

"At the beginning of April, 1741, I separated from their scales five Römer thermometers, and tested them in snow and boiling

<sup>7</sup>This winter is famous on account of its severity. According to Römer, uninterrupted frost reigned during the period covered. But in spite of the lowest temperature, which happened twice, being only 0° (Römer) = -14.3° C., the winter got its reputation for severity through the long duration of the frost. In the *Theatrum Daniae* of Pontoppidan, he says of the winter of 1709, "It was in these and neighboring countries an extraordinarily hard winter. In the woods much game froze to death and many trees died; indeed, we heard of many travelers who froze on the way. On the Baltic (Ostsee) even in the month of May sleds traveled as on highways."

<sup>8</sup>*Nordisk Universitets Tidsskrift*, 1859, p. 3, contains an essay on Römer by E. Phillipsen; in a note, p. 52, it is said: "Of his various instruments and machines there exist now, beside the remains of a barometer and a thermometer of his own make, which belong to the collection preserved in the former Art Museum." The objects mentioned I have not found listed in the catalog of 1848. Neither in Schloss Rosenborg, nor in the National Museum, whither the objects of the Art Museum were taken, was there any trace of them to be found.

water, and found after so many years exactly the same readings that Römer himself had marked with a flint."

When one sees that Römer had spent comparatively much of his closely occupied time in the construction of an "original" thermometer, there suggest themselves three questions: (1) Is this interest connected with Römer's other scientific and practical labors? (2) Did he use the thermometers so constructed for systematic measurements? (3) Did his new ideas influence others in the construction of thermometers? I will attempt an answer to these questions.

From the *Adversaria* we can conclude that the first question is to be answered, *Yes*. For two reasons: Römer wished to determine the expansion of metals by heat, partly to determine the variations with temperature of the size of a degree in an instrument in his "Observatorium Domesticum," partly to determine the temperature variation in the periodic time of a pendulum. The latter may have interested him partly on account of his astronomical observations, partly on account of his endeavors to found a system of units. Without doubt, he, in common with Picard, was planning for the introduction of a *normal foot*, in order to express in terms of it the customary length-units of different countries, and for that purpose he wished to make use of the length of the seconds pendulum. Römer and Picard assumed that this was the same everywhere on the earth.<sup>9</sup> Measurements by Picard, in Paris, and, with Römer's help, at Uraniborg, and by Römer himself at London, had in fact given the same value.

According to p. 67 of the *Adversaria* Römer had occupied himself with the expansion of various metals. It reads:

"Changes in length of metals by cold and heat, tried 12 December, 1692, three or four times."

Römer's measurements—whose method he unfortunately does not describe—showed that the lengths of three-foot rods of various metals, which he had divided into 6,800 equal parts, increased differently for equal warming. If his thermometer read 6 1-2 in the cold and 30 1-2 when heated, or rose 24, then the 6,800 parts increased:

For gold and copper.....	5	parts
For silver and tin.....	6 1-2	parts
For lead.....	9 1-2	parts
For iron (at most).....	3 1-2	parts
For glass, a round tube of 1-2 inch diameter.....	3 1-2	parts

<sup>9</sup>I find this hard to understand, as Romer, 1672-3, was one of the observers who worked at Paris simultaneously with Richer at Cayenne for determining the solar parallax by observations on Mars, etc.; he could, therefore, hardly have been ignorant of the way Richer's clock varied with the latitude, when the clock was set up at Paris and at Cayenne, nor of the controversy that ensued.—W. J. F.

so that a fiber of lead increased about 1-10 inch, of gold or copper about 1-2 inch, of tin or silver 1-15 inch, of iron and glass 1-3 inch.

"Now my instrumentum domesticum<sup>10</sup> can easily be kept between the cold 6 and the warmth 16, which consequently corresponds to a difference of at most eight parts on the thermometer; or, better, between eight graduations, which is a third of that observed.

"Later I added this; a higher temperature can be avoided; but cold can depress the fluid to graduation 4 near the window, where the instrument is, as I have just observed. A difference in cold and warmth of 11 and 12 is therefore to be expected; i. e., half as much as I observed in case of the rods."

The instrument here mentioned, Römer's famous meridian instrument, is figured in Horrebow's *Basis Astronomiae*. In the picture we see beside the telescope of the meridian instrument a clock, serving for the necessary determination of time. Probably Römer calculated the changes in rate of this instrument due to temperature changes. The fact is, that the iron pendulum rod altered in length 1-100 line for each thermometer degree, but a change in length of 1 line increases or decreases the rate 1 second in 24 hours.

Further, an apparatus is sketched<sup>11</sup> for making comparative measurements of the expansion of air and liquids by heat. It consists of a glass bulb, 1 1-2 inches in diameter, with a narrow neck, of which a length 16 1-3 inches is equal in volume to 1-22 of the bulb. Were the tube filled with water at 8° to *a*, then on heating 10° the water expanded to *b*, a point 1 3-4 inches distant from *a*, so that the expansion amounted to 1-200 of the original volume; were the bulb filled with air, inclosed by a drop at *a*, the air expanded on heating 3° to *c*, 12 inches from *a*, and on heating 10°, and with a sufficiently long tube, would have expanded 40 inches along the tube, or 1-9 of the original volume.

The increase in volume of air on 10° heating is consequently 22 times as great as that of water. Römer adds, that he had previously got the number 24; however, the later experiments were better. According as we assume that the 8° of Römer correspond to 0° C. or 15° C., we get a poor or a good agreement with modern measurements.

<sup>10</sup>The "Observatorium Domesticum" was founded 1689-90. It is described in Horrebow's *Operum mathematico-physicorum*, Tom. III, p. 47. (Figures of Römer's instrumentum domesticum, etc., are found in H. H. Kritzinger, *Die Errungenschaften der Astronomie*, p. 69, Weimar 1912; L. Ambronn, *Handbuch der Astronomischen Instrumentenkunde*, II, p. 905-907.)

<sup>11</sup>*Adversaria*, p. 5.

There exists a series of measurements of the air temperature at Copenhagen in the winter of 1709, made with the new thermometers. These measurements are of especial interest, and were occasionally mentioned in foreign literature.

The winter of 1709 was very severe. In an essay entitled, "The History of the Great Frost in the Last Winter, 1708 and 1708-9,"<sup>12</sup> Dr. Derham writes of the conditions in Denmark. From his discussions we see how great was the progress of Römer, and how far his fundamental idea lay from that of his time, as Derham did not at all understand the principle of his thermometer graduations. Derham writes: (p. 458) "As to the Northern Parts, the before commended Dr. Woodward tells me, that in a letter he received from the learned Mr. *Otho Sperling*, from *Copenhagen*, dated *April 6, 1709*, he calleth it *Hymens Atrocissima*. And I find it noted in the minutes of the *Royal Society* of *May 4, 1709*, 'That Dr. *Judichar* said the ice was frozen in the harbour of *Copenhagen* 27 inches; and that *April 9, N. S.*, People had gone over between *Schone* and *Denmark* on the ice,' which Accounts give me a better Opinion of some Papers I have by me, which were showed to the *Society*, concerning the Frost at *Copenhagen*, pretended to be taken from the Observations of Mr. Römer. I should not entertain the least distrust of the Accuracy either of the Instruments or Observations of that eminent Person, were I sure they were his. But there were some Passages and Hints in those Papers that lessened others, as well as my Opinion about them. 'Tis said there, "That such a Frost hath not been known in the Memory of Man in these Countries, and that the Frost on *January 7*, and *February 23, 1708-9*, did very nearly approach the Point of Artificial Freezing."

If we examine the tables of Römer's temperature observations in 1708-9, in the *Adversaria*, it appears that it begins 26 December, 1708, and continues to 9 April, 1709; although from 1 April, 1709, on, observations are not entered for every day,

<sup>12</sup>Dr. W. Derham was a clergyman of the Anglican Church at Upminster, and a frequent contributor to the Royal Society, on meteorological and other subjects. The following quotation is pertinent, though not given by K. Meyer:

W. Derham, *Roy. Soc. Phil. Trans.*, 26, p. 335, 1709.

Speaking of a comparison of his own thermometer observations at Upminster with those of Dr. Joh. Ja. Scheuchzer, in Zurich, he says: "I. For the *Thermometer*: It would have been in vain to have compared his Observations with mine, by reason we have not got a standard for Thermometers, as we have for the Barometers; they being everywhere in all, or most respects, different; some with large, some with small Bottles of Spirits; some accordingly with longer, some with shorter; some with wider, some with narrower Canes, or Shanks; some filled with more highly rectified, and consequently more expansive Spirits, some with more phlegmatic and duller Spirits.

The quotation in the text is from *Roy. Soc. Phil. Trans.* 26, p. 454, 1709.

"The History of the Great Frost in the last Winter, 1708 and 1708-9, by the Rev. Mr. W. Derham, Rector of Upminster, F. R. S.

doubtless because the table was to record only temperatures under 8°. The notes in the margin are Horrebow's; above the table there stands: "Römer consequently had changed his first proposition." That means, as Horrebow's marginal notes in the *Adversaria* show, that Römer had made the number 8 the melting point, instead of 7 1-2 as previously.

Now the table shows that exactly on 23 February, which Derham mentions specially, the thermometer sank almost to Römer's zero point. Recall the expression with which Derham refers to this fact: "that the Frost on *January 7* and *February 23*, 1708-9, did very nearly approach the Point of Artificial Freezing." From this it follows that Römer's zero point was exactly the temperature of a freezing mixture,<sup>13</sup> a fact which Derham himself must have got from the information originating in Denmark, as he did not know Römer's scale. The remark has particular interest for the treatment of the question, whether, and if so, in what ways, Römer's thermometer became important to wider circles. The answer is, through Römer's influence on Fahrenheit.

We have direct expressions on this point, first by Boerhaave. He asserts that water can exist in the fluid state at temperatures above 32° Fahrenheit. In this connection he narrates<sup>14</sup> that "the distinguished mathematician Römer in the year 9 of this century observed in Danzig a winter cold<sup>1</sup> (down) to the first degree of this same thermoscope, of which he was himself the inventor."

Here Römer is expressly represented as the first maker of Fahrenheit thermometers. Boerhaave's statement has double importance, as he stood in close relations with Fahrenheit, who had made him thermometers, and whose skill as instrument maker he often mentions with praise. The statement that Römer made measurements in Danzig in 1709 rests on a misunderstanding; as we shall see below, measurements were made with a similar thermometer in Danzig, not by him, but by others. At all events it cannot be shown that Römer was then abroad; his numerous official duties, his delicate health,<sup>15</sup> and particularly the table of temperatures at Copenhagen make this doubly improbable.

<sup>13</sup>See translator's note at end.

<sup>14</sup>H. Boerhaave, *Elementa Chemiae, Lugduni Batavorum*, 1732, T. I, p. 720.

<sup>15</sup>His death in 1710 was due to stone, from which he suffered a long time.—W. J. F.

We find also other statements that Römer was the true inventor of the Fahrenheit thermometer. These can frequently be referred back to Boerhaave. So the English physician Martine writes<sup>16</sup> that the quicksilver thermometers were first invented by Römer; but as he at the same time refers to the just-quoted passage in Boerhaave, we see that he confused the invention of the Fahrenheit thermometer, which was Römer's, and that of the quicksilver thermometer.

In Danzig the matter was gossip, apparently. Hanow writes in Danzig, 25 February, 1736<sup>17</sup> ". . . According to the most accurate weatherglasses, which Herr Römer in Danzig has designed, and which Herr Fahrenheit makes the best, water boils at 212 and freezes at 32 degrees."

In a later enlarged edition of this book by Titius, Leipzig, 1753, reference is made directly to Boerhaave, which Hanow did not. Hanow's views apparently varied. In an essay of 1745 by v. Bergen it is said of Fahrenheit, "To whom Römer, that very zealous friend of the physical and astronomical sciences, had suggested the freezing and boiling limits in the construction of thermometers, if we may believe Hanow in the *Memorabilia Gedanensia*."<sup>18</sup> This expression has in recent times led E. Gerland, in connection with Hanow, to assert that it was Römer who suggested to Fahrenheit the applicability of freezing point and boiling point in the temperature graduation. At the same time Gerland tries to limit this credit; among other things he says<sup>19</sup> that Fahrenheit's discovery of supercooling<sup>20</sup> taught him to use the melting point of ice, and not, as Römer had advised him, the freezing point of water. As appears from Römer's own papers, he used exactly this melting point of snow, so that it is not probable he advised Fahrenheit otherwise.

Later, Hanow gave up his above-mentioned view about Römer's influence on Fahrenheit, for in the second edition of his treatise, 1757, v. Bergen says<sup>21</sup>:

"In the first edition of this work I say that Fahrenheit owed the excellent idea of these fixed points (freezing point and boiling point) to the keen-minded Römer; but to assert this now I am

<sup>16</sup>Essays Medical and Philosophical, August, 1738; in an essay on thermometers.

<sup>17</sup>Erläuterte Merkwürdigkeiten der Natur, p. 62; (a sort of weekly, published by Hanow.)

<sup>18</sup>De thermometris mensuræ constantis Commentatio Francfortii ad Viadrum 1745.

<sup>19</sup>E. Gerland u. F. Traummüller, Geschichte der Experimentierkunst, 1899, p. 249, p. 251.

<sup>20</sup>Roy. Soc. Phil. Trans., 33, p. 81, 1724-5.

<sup>21</sup>v. Bergen, Commentatio de Thermometris, 2. ed., Nurnberg, 1757, p. 22, note.

forbidden, by a letter which the famous Hanow has written me, in which he says, Römer's arrangement was derived from the then customary graduation of thermometers in the Académie des Sciences at Paris, introduced, if I remember correctly, by de la Hire . . . . I assent gladly, for I do not at all understand by what accident this important invention was reserved for Fahrenheit, a quite uneducated man; for de la Hire's thermometer is not provided with these fixed points."

We now know certainly that Hanow's account of Römer's scale is inaccurate, but even the fact that he gives it shows that he knew of the existence of a Römer thermometer, without knowing the thermometer itself. Consequently, Gerland's suspicion is untenable, that Hanow had his information from Fahrenheit; further, Gerland says of Fahrenheit, that in 1710 he came to Danzig, and in fact from Copenhagen, where he visited Römer in 1709.

Thus we come to the question, Can an influence of Römer on Fahrenheit be proved, and in what direction? In his biography of Fahrenheit Professor Momber collects<sup>22</sup> what is known with certainty about Fahrenheit's dwelling places at various times; he does not believe that it can be fixed, when Fahrenheit visited Römer; but that he did visit him he regards as settled. Also, the principal source of our information about Fahrenheit's youth, a manuscript in the Royal Library in Berlin, makes this probable; here it is related, that as late as 1706 Fahrenheit was making many laborious journeys on land and water, and had conferences with the famous mathematicians in Denmark and Sweden.<sup>23</sup>

<sup>22</sup>*Schriften der Naturforschenden Gesellschaft in Danzig*, N. S. 7, p. 108, 1890.

<sup>23</sup>My authority here is the *Altpreussische Monatsschrift*, 1874, in which Strehlke has published a fragment of Wuttstrack's "Collectaneen" (materials collected) for his unpublished work, *Historisch-topographisch-statistische Nachrichten von Danzig*. Bialystok, 1804.

In a volume of collections in the Royal Library at Berlin, there is the following account, by a foreign hand of the eighteenth century, in the chapter on famous Danzigers (Fahrenheit 1686-1736, written 1740): "It is related of his childhood that he was really destined for study, and then—"But by the unexpected and sudden death of both his parents, who left this world 1701, 14 August, in their garden house, this plan was set back, since his guardians found it advisable to dedicate him to trade. To this, therefore, he was obliged to yield (though not without revolt) and (after he for some time received the necessary instruction in bookkeeping) Anno 1702, was sent to Amsterdam to learn the business with Hermann von Beuningen, now dead, where also he remained for the stipulated four years' service; but, instead of continuing in business, his so long hindered natural inclination toward studies spurred him on anew to follow his intended goal. To that end he made many laborious journeys on water and land, conferred with the most famous mathematicians in Denmark and Sweden, sent his instruments to Iceland, Lapland and other places, whence the observations made by interested people were sent to him at Amsterdam; and it is well known (wie den notorisch) that already, Anno 1709, in the severe winter he had made very noteworthy observations with his weatherglasses, of which mention was made in various news items on the occasion of the severe cold occurring in this 1740th year. Ao. 1710, after the end of the pest, he visited his blood friends in Danzig 1711, he went to Kurland and Liffland, whence, 1712, he returned and cultivated intimate relations with the then living Professor Math. Paul Pater. Ao. 1714, he traveled to Berlin and Dresden, in order to superintend in person the manufacture of the tubes for his instruments in the glass works there, from whence later to Amsterdam, where afterwards he lived continuously." (Beside these journeys, Fahrenheit lived in England at dates not recorded in the reference books which I have examined.—W. J. F.)

On this Momber says, "These statements seem to me to be especially reliable, since in the first place, as far as they can be checked by source documents, they are found to be true, and, further, written down four years after Fahrenheit's death, their whole character points toward an author who stood in very close relations with him and his family." Professor Momber was so friendly as to communicate to me that he has later found nothing giving definite information about the relations between Fahrenheit and Römer.

From the manuscripts mentioned it is clear that between 1702 and 1710 Fahrenheit was in Denmark and in relations with Römer, that is, exactly at the time when Römer was working on his new thermometers. In Titius' *Oddities of Nature* it is several times mentioned that, 1709, measurements of temperature were made "with the weatherglass of Fahrenheit, famous in Danzig on account of its accuracy, and in use as early as 1709."<sup>24</sup> Further, he says of this weatherglass, "Wilki's weatherglass, which Krikart owned and described in the year 1709, also agrees. Since this Krikart is said to have owned such a glass as much as twenty years before 1709, but not to have described it before 1708, it seems to have been filled at the beginning of the frost in the year 1708 with fresh spirits by Fahrenheit, and to have been arranged according to his method."<sup>25</sup>

Consequently, it is probable that Fahrenheit met Römer, and, if Boerhaave's statement is correct, in the oldest Fahrenheit thermometers we must trace Römer's influence.

From Römer Fahrenheit could learn the following: the principle of two fixed points as basis of the scale, and the graduation in equal volumes. Fahrenheit has described the construction of his thermometers only briefly<sup>26</sup>;—

" . . . . Two sorts of thermometers are principally made by me, one filled with spirits of wine, the other with quicksilver. Their length varies according to the use they are to serve. They are all alike in this, that the degrees of their scales agree among themselves, and that their variations occur between fixed limits. The scales of thermometers which are intended mainly for meteorological observations begin below at zero and end at the 96th degree. The division of this scale rests on three

<sup>24</sup>Titius, *Seltenheiten der Natur*, p. 666.

<sup>25</sup>*l. c.*, p. 693.

<sup>26</sup>*Roy. Soc. Phil. Trans.*, 33, p. 78, 1724. (This is in Latin: I have translated directly, and somewhat more at length than K. Meyer, rather than retranslate from the German.—W. J. F.)

fixed limits, which are determined in the following manner: the first of them is found at the bottom or beginning of the scale, and is got with a mixture of ice, water and sal ammoniac or sea salt; if the thermometer is placed in this, the fluid descends to that degree which is marked zero. This experiment succeeds better in winter than in summer. A second boundary is obtained, if water and ice are mixed without the above-mentioned salts. The thermometer being placed in this mixture, the fluid reaches the thirty-second degree, called by me the boundary of freezing, for stagnant water is covered with very thin ice when in winter the fluid of the thermometer reaches this degree. The third boundary is found at the ninety-sixth degree; the spirit expands just to this degree when it is held in the mouth or armpit of a living man in good health so as to acquire perfectly the heat of the body. But if the heat of a man in fever or subject to some other fervent disease is to be tested, another thermometer is used, whose scale is prolonged to 128 or 132 degrees. Whether these degrees are sufficient for the heat of every fervent fever I have not yet found out; though it is hardly to be believed that the fervor of any fever would exceed these degrees. The scale of thermometers with which the degree of heat of boiling liquids is to be tested also begins at zero and contains 600 degrees, for about this degree the mercury (with which the thermometer is filled) itself begins to boil . . . . ."

Here then Fahrenheit tells that the goodness of his thermometers depends on the use of fixed points, between which the graduation is carried out. Of the here mentioned three fixed points only one apparently—the freezing point—corresponds to those used by Römer. From the assertions of Derham, quoted above, it appears that Römer's zero of 1709 was put equal to the temperature of a freezing mixture<sup>27</sup>, and the fact that the quicksilver in the severest winter within human memory approached this point had certainly given it a special importance, so that it is not unlikely that Fahrenheit—and perhaps Römer also—chose this limit as a fixed point for such thermometers as were not to indicate temperatures to the boiling point of water. As we shall see in the various scales of 1708 to 1714, which bear Fahrenheit's name, this fixed point was not quite definitely determined; from the words quoted above, "This experiment succeeds better in winter than in summer," we can see that Fahrenheit does not think that he always gets exactly the same temperature. The

<sup>27</sup>See translator's note at end.

third point is perhaps then introduced as a sort of check. In the earlier years Fahrenheit kept his construction secret and surprised his contemporaries in the highest degree by the agreement among his thermometers.

Fahrenheit's oldest thermometers are mentioned in various places. Grischow<sup>28</sup>, especially, gives a detailed collation of the various scales according to which they were graduated. The later discussions, of which Van Swinden's *Dissertation sur les Thermomètres*, Amsterdam, 1778, is very complete, are mainly based on Grischow. According to Grischow<sup>29</sup> and others,<sup>30</sup> Fahrenheit is said to have communicated the secret of his thermometer graduation to his instructor (Repetitor) in mathematics, Barnsdorf, of Rostock; and of it he asserted that anyone, knowing it, could make agreeing thermometers. Grischow writes that this happened about 1712 or 1713, if not earlier. Shortly thereafter Fahrenheit went to Halle and Leipzig; and Barnsdorf, in company with his colleague Lange, tried to make thermometers according to his directions. The scale of these thermometers was somewhat different from that of those which later passed under Fahrenheit's name, and it is said of Barnsdorf that he certainly "had kept Fahrenheit's older or oldest graduation." From a table it is clear that Barnsdorf's thermometers showed 7 1-2 at the freezing point and 22 1-2 at body heat; these degrees are subdivided into smaller, in fact into eight, degrees each. The use of 7 1-2 at the freezing point indicates, in connection with everything else, an influence of Römer. Barnsdorf's zero lies somewhat higher than that of the later Fahrenheit thermometer. We have also other witnesses to the fact that Fahrenheit had used 7 1-2 at the freezing point, and that his zero originally stood somewhat higher than was later the case.

Professor Kirch, Berlin, describes, 1737, his thermometer<sup>31</sup> in connection with certain temperature observations which a friend in Pennsylvania had made with a thermometer of the same sort as his own; this thermometer had been given the friend by Kirch himself, 1727, and in the essay observations by Kirch in the year 1732 are mentioned. Consequently the essay must have been written between 1732 and 1737. Kirch's discussions are contained in the following:

<sup>28</sup>Miscell. Berolenses, T. VI, printed 1740.

<sup>29</sup>l. c., p. 271.

<sup>30</sup>Cotte, *Traite de Meteorologie*, 1774, p. 129.

<sup>31</sup>Miscell. Berol., 5, p. 129, 1737.

1. My thermometer, which I have used several years, was made by the so skillful Fahrenheit more than twenty years ago. On it 24 degrees of heat are numbered; 0 denotes the greatest cold and 24 the highest heat. Two more degrees are introduced below zero, so that the degree of cold of the thermometer can be reckoned even when, in the case of extraordinary cold, its fluid contracts so as to withdraw below the limit zero.

2. This is a thermometer of small or medium size; its scale measures 5 Rhenish inches from 0 to the 24th degree. The single degrees are divided into four quadrants, so that from degree zero to the last division line there are 96 quadrants.

3. On the newer Fahrenheit thermometers the scale is no longer divided into 24 degrees and quadrants, but into 96 smaller degrees, corresponding to the 96 quadrants of the 24 degrees in which the older thermometers are divided.

4. The two sorts of graduation can easily be compared, since the quadrants of the larger degrees are quite equal to the smaller degrees.

5. Some years ago I noticed that my thermometer did not entirely agree with others of Fahrenheit, and so I ordered from the famous Mr. Fahrenheit a new and exact thermometer, so as to be able to compare with it my own and other thermometers. I found that this new thermometer agrees well with others of Fahrenheit, but differs noticeably from mine.

In paragraphs 6 and 7 Kirch treats the size of the discrepancies; at the highest and lowest temperatures they are not always the same; at the highest temperature they are 6 1-2 small degrees; at the lowest, 5, since the zero point of the old thermometers lies higher.

In 8, "The boundary between frost and thaw on my thermometer is at 7 1-2; on the new Fahrenheit thermometers at 36." (36 is correctly copied, though unexpected.—W. J. F.)

One more thermometer, perhaps the oldest of all, seems based on a graduation with fixed points and a scale like that of Barnsdorf, although the numbering is quite different. Grischow writes, 1740, that a large thermometer, made by Fahrenheit thirty years before for the Royal Society in Berlin, and consequently with every conceivable care, still agreed perfectly with a small thermometer that Fahrenheit had recently sent from Amsterdam to Berlin. These small thermometers were graduated by means of two or three fixed points and made exactly as we get them today. The first of these thermometers must therefore have been constructed according to quite definite principles<sup>32</sup>; for such an agreement cannot be accidental; a similar thermometer, used for observations 1709, surely one of the first made by Fahrenheit, was still in existence in Danzig in 1740.

This thermometer was apparently graduated like the Florentine; 90° at body heat, 0° at summer heat, 90° at the lowest degree of cold; at the freezing point of water stands 30°. From the

<sup>32</sup>Van Swinden, *Dissertation*, par. 34.

lowest degree of heat to the freezing point there are then  $60 = 8 \times 7 \frac{1}{2}^\circ$ ; from the lowest to the highest heat degree  $180^\circ = 8 \times 22 \frac{1}{2}^\circ$ ; it is then apparent that this thermometer graduation is the same as Barnsdorf's, except that the large degrees are divided into eight smaller.

In 1714, Fahrenheit made two concordant thermometers for Freiherr Christian von Wolff, Chancellor of the University at Halle, who was very much pleased with them and has described them.<sup>33</sup> The scale had 26 degrees; the second degree of the scale was designated "greatest cold," and from there on to the upper end there were 24; at the eighth stood "cold." This reminds one exactly of the scale mentioned by Grischow as on the older thermometers of Fahrenheit, with the fixed points 0, 8, 24—later 0, 32, 96. Here Fahrenheit—perhaps like Römer, according to Horrebow's view,—had changed, and chosen 8 instead of 7 1-2. From this we get strong support for thinking that Fahrenheit's fixing of the freezing point at  $32^\circ$  is connected with Römer's directions for it.

In case Römer's scale is reproduced in that of Fahrenheit, one would expect to find the boiling point  $4 \times 60 = 240$ , and not 212. This can, however, be explained.<sup>34</sup> According to the above quoted descriptions of the oldest thermometers the zero of the newer thermometers lies lower than that of the older; if now these latter have the same zero as Römer's thermometer, their degrees must be shorter than those of the newer, since a shorter length contains the same number of degrees. In the newer thermometers the number of the boiling point was found by a division of the range zero (determined by a freezing mixture) to freezing point into 32 equal parts, and the continuation of this beyond the freezing point; since these degrees are longer than the older ones, there are fewer to the same range—hence 212 and not 240 at the fixed boiling point.

The thermometers of Fahrenheit, especially the quicksilver thermometers, are an extraordinarily great step in advance; by them the goal of equal indications for like thermal conditions had been closely approached. Yet till 1775 for the most part people kept on using thermometers of quite different construction, and with graduations which are only with difficulty convertible. In the writings on thermometers of those times one finds extensive tables for the conversion of long forgotten scales, as, e. g.,

<sup>33</sup>*Acta Eruditorum*, p. 381, 1714.

<sup>34</sup>See translator's note at end.

in Martine, Van Swinden and Lambert. Only three scales have endured to our time. The scale of Réaumur dates from the year 1730,<sup>35</sup> and is a backward step in comparison with Fahrenheit's; it was not originally founded on the application of two fixed points. In his graduation Réaumur used one fixed point and graduated the tube in fractions of the bulb volume. This graduation was done experimentally with the help of little pipettes and funnels; the tube could not then have been a capillary; the bulb must have been about two to three inches in diameter. So, first, this thermometer is very insensitive; second, the determination of the fixed point, the freezing point, is easily inaccurate, for much time must be spent in getting the bulb to the required temperature. Réaumur names 80° as the boiling point only in passing; he will rather make different thermometers agree by graduating their tubes by the method above described and filling them with the same fluid; he proposes to use wine spirit of a strength such that 1,000 volumes on heating from the freezing point to the boiling point of water expand to 1,080 volumes. But the method which he applies for testing this expansion can give no certain results. Later the thermometer of Réaumur was altered to its present generally known form.

Celsius<sup>36</sup> in his thermometer applies a rational sort of graduation; in doing so he takes account of the pressure variation of the boiling point of water.

#### TRANSLATOR'S NOTE.

A good and accurate account of the development of the thermometer is given by Cajori in his *History of Physics*, based largely on Gerland's book on the thermometer. As Römer's *Adversaria* was not published when these were written, his contributions are not stressed in them. But one must be on his guard against the statement that Huygens advised the employment of two fixed points. His letter of January 2, 1665, recommends the use of a tube whose volume is a known fraction of the bulb-volume, and one fixed point, either the ice point or the steam point. However, he seems to have preceded Halley and Amon-ton in observing the constancy of the water boiling point. The use of two fixed points, the melting points of ice and of butter, was advised by Dalencé, 1688.

There is discrepancy in the various books as to the date when Fahrenheit began to use mercury. But while some say that

<sup>35</sup> *Hist. et Memoires de l'Academie de Paris, annee 1730*, p. 452.

<sup>36</sup> *Vetensk. Akad. Handl. Aar, 1742*, p. 171.

he made thermometers before 1709, I think that the above account by K. Meyer renders it very improbable. She also makes clear, in agreement with others, that Fahrenheit used four scales, thus:

	Maker	Described by	Made	M.Pt.	Bl'd Ht.	B. Pt.	Zero
a	Römer.....	Römer, before 1710.....	1702-3	7.5	.....	60	-14.3°C.
b	Römer.....	Horrebow, after 1739	before 1709	-	.....	?	?
a	Fahrenheit.....	Grischow, 1740.....	1710?	-30	90	.....	+9.2°C.*
a	Fahrenheit.....	Kirch, 1732-7.....	before 1712?	7.5	.....	.....	.....
a	Barnsdorf.....	Grischow, 1740.....	1712-3	7.5	22.5	.....	-18.4°C.*
b	Fahrenheit.....	Fahrenheit, 1724.....	1724	32	96	.....	-18.4°C.*
.....	Fahrenheit.....	Kirch, 1732-7.....	about 1737	36	.....	.....	.....
.....	Fahrenheit.....	Modern texts.....	.....	32	.....	212	-17.8°C.

Fahrenheit's and Barnsdorf's *a* seem based on Römer's *a*, but have a different starting point,  $-18.4^{\circ}\text{C.}$ , (\*computed by taking the mean blood heat =  $36.875^{\circ}\text{C.}$ ;) Fahrenheit's *b* is based on Römer's *b*, whose starting point is not known; though K. Meyer asserts, on what seems the inadequate evidence of Dr. Derham's account, that it was a freezing mixture temperature. However, Fahrenheit's *a* and *b* and Barnsdorf's *a* have the same starting point,  $-18.4^{\circ}\text{C.}$

Suspensions are voiced by some authors that Fahrenheit did not describe his actual method in his Philosophical Transactions account of 1724. And it does seem hard to believe that such good agreement as his instruments are reported to have shown could have been obtained with the shifting and uncertain zero point got "with a mixture of water, ice and sal ammoniac or sea salt," an experiment which worked "better in winter than in summer."

It may also be noted that Landolt and Björnstein, 1905, give the following values for the eutectic points of the mixtures used by Fahrenheit:

Ice 100 parts	Salt 28.9 parts	-21.2°C.
Ice 100 parts	Sal ammoniac 22.9 parts	-15.8°C.

Both of these are temperatures which differ considerably from the starting points of the Römer scale,  $-14.3^{\circ}$ , and the Fahrenheit scales,  $-18.4^{\circ}$  or  $-17.8^{\circ}$ .