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A New Look at the Origin of the Heat Transfer Coefficient Concept

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ABSTRACT

Heat transfer texts generally credit Newton with the concept of the heat transfer coefficient (h). Those texts which give a specific reference cite Newton's "A Scale of the Degrees of Heat" published in the Philosophical Transactions of the Royal Society of London in 1701.

In this paper, Newton's article is examined to determine whether or not it supports the contention that Newton conceived the h concept. This examination reveals that Newton's article does not describe the h concept. Evidence in the literature clearly indicates that Fourier should be credited with the h concept.

INTRODUCTION

Heat transfer texts generally credit Isaac Newton with the concept of the heat transfer coefficient (h). Those texts which give a specific reference cite his article "A Scale of the Degrees of Heat" published in 1701 in the Philosophical Transactions of the Royal Society of London. The article was published anonymously and in Latin. An English translation was published in 1749 in the third edition of The Philosophical Transactions Abridg'd by Henry Jones. Appendix 1 is a reproduction of the 1749 translation.

In physics texts and in heat transfer texts, the 1701 article by Newton is cited as the source for what is usually called "Newton's law of cooling". Surprisingly, this law appears in three different forms:

$$\frac{d\Delta T}{dt} \propto -\Delta T \quad (1)$$

$$q \propto \Delta T \quad (2)$$

$$q/A = h \Delta T \quad (3)$$

Physics texts generally give Newton's law of

cooling in the form of Equation 1 and/or Equation 2. Heat transfer texts generally give the law in the form of Equation 3 and thereby credit Newton with the h concept.

Within the framework of twentieth century thermal science, Equations 1, 2, and 3 are extremely simple. Their seeming simplicity results because they are based on mathematical and thermal concepts which are very familiar and have been used for many decades. But in an absolute sense, Equation 2 is conceptually much more difficult than Equation 1, and Equation 3 is conceptually much more difficult than Equation 2. Note that:

- Equation 1 requires an understanding of only one thermal concept--the intensive parameter named "temperature" (T).
- Equation 2 requires an understanding of and a clear distinction between two thermal concepts--the intensive parameter "temperature" and the extensive parameter "heat" (q). Moreover, "heat" is a much more difficult concept than temperature because an understanding of heat can be gained only through the intellect, whereas an understanding of temperature is gained readily and universally through the sense of touch.
- Equation 3 requires an understanding of four thermal concepts--temperature, heat, heat flux (q/A), and heat transfer coefficient. Since the concepts of heat flux and heat transfer coefficient build on the concept of heat, they are conceptually even more difficult than the concept of heat.

The point of the above is to indicate that, with regard to thermal concepts, Equations 1, 2, and 3 are vastly different. Therefore the extent of Newton's contribution to thermal science depends strongly on which of these equations accurately reflect the substance of his 1701 article.

In this monograph, Newton's 1701 article is examined to determine the true extent of Newton's

contribution to thermal science. On the basis of evidence in the literature, this monograph also answers the question, "Who should actually be credited with the h concept?"

THE SUBJECT OF NEWTON'S ARTICLE

Even a casual reading of Newton's 1701 article (reproduced in Appendix 1) reveals that its subject is temperature rather than heat, even though the word "temperature" never appears in the article, and the word "heat" appears almost one hundred times. The main thrust of the article is Newton's proposed temperature scale based on zero degrees defined by "The Heat of Winter Air, when Water begins to freeze", and 12 degrees defined by "The greatest Heat that the Thermometer received by the Contact of a Human Body".

The first part of the article is a table which contains the "Heats" Newton measured and reported using his proposed scale of the "Degrees of Heat". The second part of the article describes the experiment he designed and performed, and the rationale behind the data reduction.

"Heats" in the range 0 to 72 degrees were obtained with a "Linseed Oyl" thermometer "by supposing the Heat of the Oyl proportional to its Rarefaction" (i.e. inversely proportional to its density).

"Heats" in the range 12 to 192 degrees were determined by placing small quantities of substances which would melt on "a piece of red hot iron" which Newton intentionally put "in a cold Place, where the Wind blew constantly". The data were "the Times of Cooling, till all the Particles grow stiff and lost their Fluidity" (i.e. the data were the elapsed times from the beginning of the cooldown to the solidification of each substance which had been placed on the iron).

Newton reduced the "Times of Cooling" data to temperatures by assuming that the "Excesses of the Heat of the Iron . . . are in Geometrical Progression when the Times are in Arithmetical Progression".

NEWTON'S LAW OF COOLING AS DESCRIBED IN PHYSICS TEXTS

Some physics texts state that Newton's law of cooling is given by Equation (1). Others state that it is given by Equation (2), and still others state that it is given by both Equations (1) and (2).

Draper (1911) describes Newton's law only in terms of Equation (1). He gives the law as

The rate of rise or fall of temperature of a body is proportional to the difference between the temperature of the body and that of the enclosure.

and writes it analytically in the form of Equation (1). Other physics texts which give Newton's law of cooling only in terms of Equation (1) are Hausmann and Slack (1957), Sears and Zemansky (1965), and Halliday and Resnick (1978).

Examples of physics texts which describe Newton's law only in terms of Equation (2) are Stewart (1866) and Brown (1952). Physics texts which describe Newton's law in terms of both Equations 1 and 2 are Cork (1933), Worthing and Halliday (1948), and Stewart and Satterly (1950).

Very few (if any) physics texts describe Newton's law of cooling in terms of Equation 3--ie in terms which include the heat transfer coefficient.

NEWTON'S LAW OF COOLING AS DESCRIBED IN HEAT TRANSFER TEXTS

Heat transfer texts generally describe Newton's law of cooling in terms of Equation 3 and credit Newton with the h concept. Giedt (1957) states:

The concept of a heat transfer . . . coefficient was introduced by Newton in 1701. (15) He recommended the following equation to describe convective cooling of objects:

$$q = h A (T_{\text{surface}} - T_{\text{fluid}}) \quad (1.9)$$

. . . this is often referred to as Newton's Law of Cooling.

(15) Phil. Trans. Roy. Soc., London, 22, 824 (1701)

Jakob (1949) states:

For heat convection the following equation was first recommended by Newton (1701):

$$q = h A \Delta T \quad (1-2)$$

It is often called "Newton's cooling law". Newton, I., Phil. Trans. Roy. Soc. London 22, 824; 1701

In statements similar to the above and with the same reference, McAdams (1954) and Rohsenow and Choi (1961) also credit Newton with the h concept.

Many heat transfer texts credit Newton with the h concept, but cite no specific reference. For example, Holman (1981) states:

To express the overall effect of convection, we use Newton's law of cooling:

$$q = h A (T_w - T_f) \quad (1-8)$$

Here the heat-transfer rate is related to the temperature difference between the wall and fluid and the surface area A.

Eckert and Drake (1972) state:

. . . Newton introduced a linear relation between the heat flux q transferred to a solid surface per unit time and area by a fluid moving over it and a characteristic temperature difference ΔT

$$q = h \Delta T$$

. . . h is called a heat-transfer coefficient

Similar statements are also made without specific reference by Kreith (1973), Luikov (1968), Rohsenow and Hartnett (1973) and by Incropera and DeWitt (1981).

In summary, most heat transfer texts credit Newton with the h concept and Equation 3. Those which give a specific reference cite Newton's 1701 article reproduced in Appendix 1.

NEWTON'S LAW OF COOLING AS DESCRIBED BY NEWTON

Newton described his "law of cooling" in the following passages:

. . . the Heat which the Iron loses in a given time, is as the whole Heat of the Iron. Therefore

if the Times of cooling are taken equal, the Heats will be in a Geometrical Ratio, and therefore are easily found by a Table of Logarithms.

. . . the Excesses of the Heat of the Iron and the rigid Particles above the Heat of the Atmosphere found by the Thermometer, are in Geometrical Progression when the Times are in Arithmetical Progression . . .

In order to understand these passages, it is essential to know what Newton and his colleagues intended by the word "Heat"--i.e. by the Latin word "calor" which Newton used in the original manuscript. Since Newton does not define "Heat", its meaning must be obtained from the context in which it is used in the article. Newton states:

- 0 degrees is "The Heat of Winter Air, when Water begins to freeze"
- 6 degrees is "The Heat of the Air at Noon"
- "the Heat of boiling Water is almost three Times greater than the Heat of the Human Body"
- "if the Times of cooling are taken equal, the Heats will be in a Geometrical Ratio"

From its context in the article, it is apparent that "Heat" has the singular meaning of warmth or hotness or temperature. It is equally apparent that "Heat" has nothing to do with heat in the modern, scientific sense--nothing to do with an extensive thermal parameter which describes a quantity of energy.

Newton repeatedly used the word "calor", and calor was correctly translated to "Heat". But to Newton and his colleagues, the word "Heat" meant the intensive thermal parameter now called temperature. Many decades after Newton's article, the word "heat" ceased to mean temperature to the scientist. But to the lay person, the word "heat" continued to mean temperature. Maxwell (1883) discussed the ambivalent character of the word heat:

We have nothing to do with the word heat as an abstract term signifying the property of hot things, and when we might say a certain heat, as the heat of new milk, we shall always use the more scientific word temperature of new milk.

Even today, the word heat means temperature to the lay person, as evidenced by Webster's (1968) lay definition:

heat the state of a body or of matter that is perceived as opposed to cold and is characterized by elevation of temperature: a condition of being hot; WARMTH: HOTNESS: (the iron lost its heat in contact with the cold ground)

Note that the word heat has the same meaning to the twentieth century lay person that it had to Newton and his colleagues--and that meaning is warmth/hotness/temperature.

Since the word "heat" meant temperature to Newton, the analytical expression of Newton's words quoted above is:

$$\frac{d(T_{\text{iron}} - T_{\text{atm}})}{dt} \propto -(T_{\text{iron}} - T_{\text{atm}}) \quad (4)$$

$$(T_{\text{iron}} - T_{\text{atm}}) = (T_{\text{iron}} - T_{\text{atm}})_{t=0} e^{-\lambda t} \quad (5)$$

Equations 4 and 5 are the analytical expression of the "law of cooling" described by Newton in 1701.

THE MODERN, SCIENTIFIC EXPRESSION OF NEWTON'S LAW OF COOLING

In Newton's article, the word "Heat" means the intensive thermal parameter now called temperature. Therefore, there can be no doubt that the modern, scientific expression of the law of cooling described by Newton is

The temperature which a hot object loses in a given time is proportional to the temperature difference between the object and the ambient.

And there can be no doubt that the analytic expression of the law of cooling described by Newton is given by Equation 1 or 4 or 5 and not by Equation 2 or 3.

THE ORIGIN OF THE MODERN, SCIENTIFIC CONCEPT OF HEAT

Newton and his colleagues had only a limited and qualitative understanding of an extensive thermal parameter, and did not draw a clear distinction between intensive and extensive thermal parameters. In fact, they used the same word for both parameters.

Notice in the following from Query 18 of Newton's Opticks (1706) that Newton uses the word "Heat" to mean an extensive thermal parameter, whereas in the 1701 article, he used "Heat" to mean an intensive thermal parameter:

(Suppose a vacuum bottle containing a thermometer) "be carried out of a cold place into a warm one.... Is not the Heat of the warm Room convey'd through the Vacuum by the Vibrations of a much subtler Medium than Air, which after the Air was drawn out remained in the Vacuum?"

In the above passage, the word "convey'd" indicates that "Heat" refers to an extensive thermal parameter, and demonstrates that Newton and his colleagues sometimes used the word "Heat" to mean an extensive thermal parameter. But in Newton's 1701 article, Heat obviously means temperature.

It is generally agreed that the first clear distinction between heat and temperature was made by Joseph Black in the middle of the eighteenth century. The Encyclopedia Americana (1984) states:

Until the middle of the 18th century little or no distinction was made between heat and temperature. About that time Joseph Black . . . clearly distinguished between quantity of heat and intensity of heat, as temperature was designated. He noted that the amount of heat required to raise the temperature of a unit mass of substance through one degree is nearly constant. This he called heat capacity.

The Encyclopaedic Dictionary of Physics (1961) states:

Joseph Black . . . (was) probably the first to distinguish clearly between heat and temperature

The New Encyclopaedia Britannica (15th ed.) states:

In 1760 . . . Joseph Black . . . introduced the

caloric theory . . . (and) defined the unit of quantity of heat . . . His contribution was an important one because he distinguished between heat and temperature.

The first clear distinction between heat and temperature was made in 1760, and since this distinction is essential to Equations 2 and 3, it follows that these equations cannot possibly be described in Newton's article of 1701.

Conceptually, there is an immense chasm between Equations 1 and 2. This chasm could not be bridged until a clear distinction was made between heat and temperature, and the experimental evidence was obtained which would demonstrate that specific heat is little affected by temperature. Black contributed both the understanding required to make a clear distinction, and the experimental evidence.

It is only because of Black's tremendous contribution that Equation 2 is readily obtained from Equation 1. And thus the real credit for Equation 2 belongs to Black--not Newton.

THE ORIGIN OF THE CONCEPT OF HEAT FLUX

Equation 3 defines the heat transfer coefficient to be the ratio of heat flux to ΔT . Herivel (1975) discusses the origin of the heat flux concept:

(The concept of heat flux) must be regarded as (Fourier's) most critically important and original single insight into the physical nature of the conduction of heat in solid bodies . . . Fourier's contemporaries (Laplace, Biot, and Poisson) found it excessively difficult either to understand or to accept this concept. (And they refused to accept it for more than a decade.)

. . . this is surely another example of one of those apparently simple, almost trivial, concepts in theoretical physics which nevertheless seem to require for their formulation the intervention of a Galileo or a Newton.

In the early part of the nineteenth century, Fourier conceived the heat flux concept--a gigantic conceptual leap, as evidenced by the prolonged, stubborn resistance from the most eminent physicists in the world. Since heat flux is an essential part of the h concept, it follows that h and Equation 3 cannot possibly be described in Newton's 1701 article.

THE ORIGIN OF THE HEAT TRANSFER COEFFICIENT CONCEPT

Conceptually, the principal difference between Equations 2 and 3 is that Equation 3 requires an understanding of the heat transfer coefficient concept and Equation 2 does not. Equation 2 states that the heat flow rate is proportional to the temperature difference. Equation 3 seems to state that heat flux is proportional to temperature difference, and assigns the symbol (h) to what appears to be the constant of proportionality.

(Fourier intended Equation 3 to indicate that, during convective heat transfer, heat flux and temperature difference were generally proportional. However, it has long been recognized that heat flux is not generally proportional to ΔT .)

Rather than discard Equation 3 because it does not describe convective thermal behavior in a general way, the modern practice is to retain Equation 3 and

interpret it to mean simply that h is defined to be the ratio of heat flux to temperature difference.

Adiutori (1974) pursues the alternate path--i.e. he abandons Equation 3, and formulates a new thermal science which contains no heat transfer coefficients.)

Since Fourier conceived the heat flux concept, it seems likely that he should also conceive the heat transfer coefficient concept, since the latter is a relatively small extension of the former. Fourier (1822) states that he did in fact conceive the heat transfer coefficient concept--as well as the thermal conductivity concept:

. . . the effects of the propagation of heat depend in the case of every solid substance, on three elementary qualities, which are, its capacity for heat, its own conducibility, and the exterior conducibility. . . . (The capacity for heat) is exactly defined, and physicists have for a long time known several methods of determining its value. *It is not the same with the two others; their effects have often been observed, but there is but one exact theory which can fairly distinguish, define, and measure them with precision.*

We have taken as the measure of the external conducibility of a solid body a coefficient h, which denotes the quantity of heat which would pass, in a definite time (a minute), from the surface of this body, into atmospheric air, supposing that the surface had a definite extent (a square metre), that the constant temperature of the body was 1, and that of the air 0, and that the heated surface was exposed to a current of air of a given invariable velocity. This value of h is determined by observation.

We have taken this coefficient K, which enters into the (above) equation, to be the measure of the specific conducibility of each substance . . .

Fourier's claim to the h concept is validated by Herivel (1975) who compares Fourier's treatment of surface heat transfer with that of his well known contemporaries:

Since Fourier's boundary condition does no more than tie together the flow of heat up to, but just beneath, the surface with the actual flow at the surface, it is surprising to find that it was one of the aspects of the 1807 memoir criticized by Biot and Laplace (and by Poisson).

Laplace's (and presumably Biot's) views on the question are given at the end of the section on heat in Laplace's 1809 paper on diffraction. There he assumes that the surface of a heated body rapidly reaches that of the surrounding medium, and that a law is then quickly established governing the rise of temperature within the body up to a certain maximum value U. The loss of heat is then proportional to U.

It is important to note that this view expressed by Laplace in 1809 and endorsed by Biot considers that temperature is continuous at solid/fluid boundaries--i.e. that the surface of any object immersed in any fluid rapidly reaches the fluid temperature--i.e. that the heat transfer coefficient at any surface in any fluid is essentially infinite. (Grattan-Guinness (1972) states that Poisson also shared this view.)

Laplace, Biot, and Poisson were physicists of the first rank. Since they had no understanding of convective heat transfer in the same time period in

which Fourier's understanding was quite complete, Fourier's claim to the heat transfer coefficient concept is undoubtedly accurate.

FOURIER AND HEAT TRANSFER

The evidence in the literature clearly indicates that Fourier should be credited with several fundamental concepts of modern heat transfer. Fourier's credits include:

- the concept of heat flux
- the concept of heat transfer coefficient
- the concept of thermal conductivity
- the solution of boundary condition problems by matching the internal and external flux at the boundary

It is nothing short of amazing that, almost 200 years after its publication, Fourier's treatise on heat transfer is conceptually quite modern.

CONCLUSIONS

The evidence in the literature clearly indicates that:

- Equation 1 is the only form of Newton's law of cooling described in his 1701 article.
- Equation 1 is the only form of Newton's law of cooling which should be credited to Newton.
- Newton had no understanding of heat flux. Therefore, he could not possibly have conceived the heat transfer coefficient concept.
- Joseph Black bridged the gap between Equations 1 and 2 by clearly distinguishing between heat and temperature, and by his experimental results which demonstrated that specific heat little depends on temperature.
- Fourier should be credited with several of the fundamental concepts of modern heat transfer, including the heat transfer coefficient and Equation 3.

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APPENDIX 1
 NEWTON'S 1701 ARTICLE
 FIRST ENGLISH TRANSLATION (1749)

The Philosophical Transactions

A B R I D G ' D .

P A R T II .

Containing the
 P H Y S I O L O G I C A L P A P E R S .

C H A P . I .

Physiology. Meteorology. Pneumatics.

0	I.	T	HE Heat of Winter Air, when Water begins to freeze. This Heat is known by rightly placing the Thermometer in Snow pressed together, at what Time it begins to thaw.	<i>A Scale of the Degrees of Heat, by . . . n. 270. p. 824.</i>
0, 1, 2.			The Heat of Winter Air.	
2, 3, 4.			The Heat of the Air in Spring and Autumn.	
4, 5, 6.			The Heat of the Air in Summer.	
6.			The Heat of the Air at Noon, about the Month of July.	
12.	1		The greatest Heat that the Thermometer receives by the Contact of a Human Body. This Heat is much the same as that of a Bird sitting upon her Eggs.	
14	1½		The Heat of a Bath, which is almost the greatest that any one can endure long, with his Hand agitated and immersed in it. The same almost is the Heat of Blood just let out.	
17	1½		The greatest Heat of a Bath that any one can endure long, his Hand being immersed and at rest in it.	
20	1½		The Heat of a Bath in which Wax swimming and melting, by moving about grows hard and loses its Transparency.	
24	2		The Heat of a Bath in which Wax swimming grows liquid by the Heat, and is preserved in continual Flux without Ebullition.	
28	2½		The intermediate Heat between the Degrees in which the Wax melts and the Water boils.	
34	2½		The Heat by which Water boils violently, and a Mixture of two Parts of Lead, of three Parts of Pewter, and	

A Scale of the Degrees of Heat.

			and of five Parts of Bismuth grows stiff in cooling. Water begins to boil by a Heat of 33 Parts, and in boiling conceives a Heat of more than 34½ Parts. But Iron with a Heat of 35 or 36 Parts ceases to excite an Ebullition, when hot Water is dropt upon it; and of 37 Parts, when cold Water does the same.
40	2½		The least Heat by which a Mixture of one Part Lead, of four Parts Pewter, and of five Parts Bismuth, grows hot and melts, and is preserved in a continual Flux.
48	3		The least Heat by which a Mixture of equal Parts of Pewter and Bismuth melts. This Mixture cools and coagulates by a Heat of 47 Degrees.
57	3½		A Heat by which a Mixture of two Parts of Pewter, and one Part of Bismuth is melted, as also a Mixture of three Parts of Pewter, and two Parts of Lead. But a Mixture of five Parts of Pewter, and of two Parts of Bismuth, cools and grows stiff with this Heat. And a Mixture of equal Parts of Lead and Bismuth does the same.
68	3½		The least Heat by which a Mixture of one Part of Bismuth, and eight Parts of Pewter is melted. Pewter alone is melted with a Heat of 72 Parts, and cools and grows stiff by a Heat of 70 Parts.
81	3½		The Heat by which Bismuth is melted, as also a Mixture of four Parts of Lead, and one Part of Pewter. But a Mixture of five Parts of Lead, and one Part of Pewter, grows stiff when melted, and cools in this Heat.
96	4		The least Heat by which Lead is melted. Lead grows hot and melts in a Heat of 96 or 97 Parts, and cools and grows stiff in a Heat of 95 Parts.
114	4½		The Heat by which Bodies heated in the Fire by cooling quite leave off to shine in the Darkness of the Night, and again by growing hot begin to shine in the same Darkness, but with a very faint Light which can hardly be perceived. In this Heat a Mixture of equal Parts of Pewter and Regulus Martis will melt; but a Mixture of seven Parts of Bismuth, and four Parts of the same Regulus Martis, will cool and grow stiff.
136	4½		The Heat by which Bodies heated in the Fire grow red hot, but not so in the Twilight. By this Heat a Mixture of two Parts of Regulus Martis, and of one Part of Bismuth, as also a Mixture of five Parts of Regulus Martis, and one Part of Pewter, by cooling grows stiff. The Regulus by itself grows stiff with a Heat of 146 Degrees.

A Scale of the Degrees of Heat.

161	4½	The Heat by which Bodies heated in the Fire plainly grow red hot in the Twilight, just before the Rising or Setting of the Sun, but not so in open Day-light, or but very obscurely.
192	5	The Heat of burning Coals in a small Kitchen Fire, made of bituminous fossile Coals, and without blowing with Bellow ^s . The same is the Heat of Iron in such a Fire, that grows red hot as much as it can. The Heat of a small Culinary Fire made of Wood is something greater, perhaps of 200 or 210 Degrees. But the Heat of a large Fire is something greater still, especially if provoked by the Use of Bellows.

In the first Column of this Table we have the Degrees of Heat in Arithmetical Progression, beginning the Computation from that Degree in which Water begins to freeze, as it were from the lowest Degree of Heat, or the common Limit of Heat and Cold, and making the external Heat of a Human Body to be 12 Degrees. In the second Column are had the Degrees of Heat in Geometrical Progression, so that the second Degree is as great again as the first, the third as great again as the second, and so on; and the first is the external Heat of the Body of a Man adequate to Sense. Now it appears from this Table, that the Heat of boiling Water is almost three Times greater than the Heat of the Human Body, and that the Heat of melted Pewter is six Times greater, and the Heat of melted Lead is eight Times greater, and the Heat of melted Regulus is twelve Times greater, and that the ordinary Heat of a Culinary Fire is 16 or 17 Times greater, than the same Heat of a Human Body.

This Table was constructed by the help of a Thermometer and a piece of red hot Iron. By the Thermometer I found the Measure of all the Degrees of Heat, till I came to the Heat with which Pewter is melted, and by the red hot Iron I found the Measure of the rest. For the Heat which red hot Iron communicates to cold Bodies which are contiguous to it, in a given time, that is, the Heat which the Iron loses in a given time, is as the whole Heat of the Iron. Therefore if the Times of cooling are taken equal, the Heats will be in a Geometrical Ratio, and therefore are easily found by a Table of Logarithms.

Therefore first I found, by a Thermometer constructed with Linseed Oyl, that when the Thermometer was put into melting Snow, the Oyl took up a Space of 10000 Parts. The same Oyl rarified by a Heat of the first Degree, or by that of a human Body, took up the Space 10256; and by the Heat of Water just beginning to boil, it took up the Space 10705, and by the Heat of Water boiling vehemently it took up the Space 10725, and by the Heat of melted Pewter cooling, when it began to be stiff and put on the Consistence of an Amalgama, it took up the Space 11516, and the Space 11496 when it was quite stiff. Therefore the rarified Oyl was to the dilated in the

Ratio

Dr. Hook's Marine Barometer.

Ratio of 40 to 39, by the Heat of the human Body; in the Ratio of 15 to 14 by the Heat of boiling Water; in the Ratio of 15 to 13 by the Heat of cooling Pewter, when it began to grow stiff and coagulate; and in the Ratio of 23 to 20 by the Heat by which cooling Pewter grows quite stiff. The Rarefaction of Air with equal Heat was ten times greater than the Rarefaction of Oyl, and the Rarefaction of Oyl was about 15 times greater than the Rarefaction of Spirit of Wine. And from what is here found, by supposing the Heat of the Oyl proportional to its Rarefaction, and for the Heat of the human Body writing 12 Degrees, the Heat of Water when it begins to boil will come out 33 Degrees, and when it boils vehemently 34 Degrees; and the Heat of Pewter either when it melts, or when it begins to cool and becomes of the Consistency of an Amalgama, will be of 72 Degrees, and when it cools and grows hard, of 70 Degrees.

These things being known, that I might find the rest, I heated a thick piece of Iron till it was red hot, and taking it out of the Fire with a hot pair of Pincers, I immediately put it in a cold Place, where the Wind blew constantly; and putting upon it little Particles of different Kinds of Metals, and other Bodies that would melt, I observed the Times of Cooling, till all the Particles grow stiff and lost their Fluidity, and the Heat of the Iron was equal to the Heat of the human Body. Then supposing that the Excesses of the Heat of the Iron and the rigid Particles above the Heat of the Atmosphere found by the Thermometer, are in Geometrical Progression when the Times are in Arithmetical Progression, all the Degrees of Heat became known. I placed the Iron in a Wind blowing uniformly, and not in a quiet Air, that the Air heated by the Iron might always be carry'd away by the Wind, and the cool Air might succeed in its Place with an uniform Motion. For thus equal Parts of the Air would be made hot in equal Times, and would conceive a Heat proportional to the Heat of the Iron.

Now the Heats thus found will have the same Proportion to one another with the Heats found by the Thermometer, and therefore we have rightly assumed, that the Rarefactions of the Oyl are proportional to its Heat.

An Account of Dr. Hook's Marine Barometer, by Mr. E. Halley, n. 169. p. 791.

II. Dr. Hook, who has made many Attempts to improve the *Barometer*, and to render the minute Divisions on the Scale thereof more sensible, judging that it might be of great Use at Sea, contrived several Ways to make it serviceable on Board a Ship; one of which he explained to the *Royal Society* at their weekly Meeting in *Gresham-College*, *January 2. 1667*. since which Time he hath further cultivated the Invention, and some Years ago produced before the said *Society*, the Instrument I am now to describe.

The Mercurial Barometer requiring a perpendicular Posture, and the Quicksilver vibrating therein with great Violence upon any Agitation, is therefore incapable of being used at Sea, (though it hath lately