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HEAT

Abstract

The term ‘heat’ originates from the Old English word hǣtu, a word of Germanic origin; related to the Dutch ‘hitte’ and German ‘Hitze’. Today, we distinguish three different meanings of the word ‘heat’. First, ‘heat’ is understood in colloquial English as ‘hotness’. There are, in addition, two scientific meanings of ‘heat’. ‘Heat’ can have the meaning of the portion of energy that changes with a change of temperature. And finally, ‘heat’ can have the meaning of the transfer of thermal energy from a hotter to a colder system or body.

By contrast, for the Ancients and Scholastics, ‘heat’ was a manifest, real quality of bodies and there was an ontological distinction between biological or innate heat (which was regarded as an innate principle of life for warm-blooded animals) and the physical manifest heat of external objects, which is potentially harmful. During the late Renaissance period, however, both views changed fundamentally and evolved - via the application of physical and mechanical analogies - into the foundations for today’s unified mechanistic theory of heat.

Heritage and rupture with tradition

Heat as a principle of nature

In the 16th century, several innovators began to criticize the Aristotelian philosophy that had dominated the Middle ages. Several *novatores* started to criticize hylomorphism and argued that nature had to be explained by its own principles. Heat was considered to be one of these principles. For instance, Bernardino Telesio (1509-1588) launched an attack on mediaeval Aristotelianism and argued, instead of postulating matter and form, that existence is based on matter and force. (Boenke 2013) According to the author of *De rerum natura iuxta propria principia* (1565), this force has two opposing, active principles: heat (which expands), and cold (which contracts). These two processes account for all the diverse forms and types of existence. Other *novatores* such as Giordano Bruno (1548-1600) - who was an admirer of Telesio – also distinguished the two contrary forces: heat and cold. Tomasso Campanella (1568-1639) rejected the fundamental Aristotelian principle of hylomorphism (Ernst 2014) and adopted instead Telesio's understanding of reality in terms of the principles of matter, heat, and cold, which he combined with Neoplatonic ideas derived from Marsilio Ficino (1433-1499).

Innate heat of warm-blooded animals

For the early Greek medical and philosophical writers, innate heat became the single most important power in the animal system (Mendelsohn 1964). It was responsible for all essential functions such as generation and growth. For Aristotle, the source of internal warmth is in the heart (or in a corresponding organ in creatures that don't have a heart) and heat is treated as the source of life and of all its powers: nutrition, sensation, movement and thought. Moreover, the conservation of innate heat coincided with life, and its destruction with death. Plato, however, restricted the influence that vital heat had on life and death. The author of the *Timaeus* made sure that the sphere of the psyche was not affected by the vital heat or lack of it.

For more than 1500 years Claudius Galenus (AD 131 – c. 201/c. 206) dominated Western medical theory. During the renaissance, Vesalius and others translated many of his Greek texts into Latin. For Hippocrates (c. 460 – c. 370 BC) good health was the result of an equilibrium between four *humores*. Galenus linked these *humores*, however, to four basic qualities: heat, cold, moist and dry. Galen's conception of innate heat shares a great deal with the formulations in the works of other Greek physicians and philosophers. Heat is considered to be inherent in the body, its origin unclear, but closely tied to life itself. Ibn Sina, better known as Avicenna (980 – 1037), was strongly influenced by

Galen. (Siraisi 1978) The author of the *Canon of Medicine* [*Al-Qanun fi al-Tibb*] identified internal heat with vitality and differentiated it from foreign or external heat which is harmful to bodily heat. Likewise, in the early sixteenth century, Jean Fernel (1497-1558) argued that there is a distinction in nature between the innate heat of living organisms and fire. The sphere of the stars was the source of innate heat. Therefore, innate heat was not derived from fire but from quintessence or aether, thus resembling the heat of the sun. Aristotle had made a similar point in *De generatione animalium*.

In the first half of the 17th century, early scientists such as William Harvey, René Descartes and Jan Baptist van Helmont started to think about biological heat differently as a result of new discoveries. They became more and more convinced that biological phenomena such as biological heat could be explained by the same theories that concern processes in the non-living world. This approach had, in a sense, already been anticipated by Galen who compared the production of heat from foods to the process of combustion as it occurs outside the body. However, this vision only reached its definitive breakthrough during the 17th century thanks to the emerging science.

In his masterpiece *De humani corporis fabrica libri septem* (1543) Vesalius (1514-1561) gave a detailed description of the anatomy of a human being. William Harvey (1578-1657) was the first known to describe completely the circulation of blood. During his lifetime, the English physician developed a different vision of the role of heat in living organisms. Harvey no longer considered the heart to be the source of blood's innate heat. Moreover, the author of *On the Motion of the Heart and Blood in Animals* (1628) did not truly seek a real explanation or cause for it. The experimental philosopher linked internal heat closely with blood. Heat had no existence apart from blood just as blood without heat is no longer blood. In other words, heat was reduced to one of blood's important properties.

Descartes (1596-1650) supported Harvey's theory of the circulation of blood but differed fundamentally in his view of the motion of the heart. Descartes developed a theory that posits an intense heat in the heart. According to Descartes, the heart is a kind of container in which the blood is heated. The French philosopher argued that blood entering the ventricles of the heart, drop by drop, was caused "to expand and dilatate, as liquids usually do when they are allowed to fall drop by drop into some very hot vessel". Subsequently, the blood expands and rarefies and is driven through the aorta into the arterial system. Descartes treated the human body as a machine powered by the intense heat maintained in the heart, which he considered to be the motor or source of that heat. Remarkably, the concept of heat utilized by Descartes is similar to the concept of innate heat proposed by Aristotle.

The iatrochemists of the 17th century tried to apply chemical theory to various individual phenomena. Jan Baptist van Helmont (1580-1644) for instance, argued that heat is not an inherent quality of the living organism and that consequently heat cannot not be the cause of vital phenomena. The Flemish chemist stated that heat can generate nothing but heat. In his *Oriatrike or Physick Refined* (1662), he asked how cold-blooded animals could live if food was digested by virtue of the body's internal heat? The Flemish chemist, physiologist, and physician claimed that the heat in the heart is caused by a process of fermentation , similar to processes in the nonorganic world, and he suggested that digestion was aided by a chemical reagent, or 'ferment', within the body. Consequently, heat became external to the body and the cause of heat was understood in a similar way to other fermentation processes which occur outside the body.

Innovative and original aspects

External heat of bodies versus heat as an affection

For Galileo, hotness itself was not an observable, manifest quality. On the contrary, as the author of the *Dialogo* (1632) explains in paragraph 48 of his *Assayer* [*Il Saggiatore*] (1623) what we call hotness is an affection or a sensation of the body that the mind senses. In this polemic work, Galileo introduced his well-known distinction between primary properties and secondary qualities such as heat (Buyse 2015). In this work, Galileo defines a body as a piece of matter and he emphasizes that primary properties are closely linked to that matter, thereby rejecting the peripatetic concept based on matter and form as well as all sorts of occult qualities (which were so important for renaissance philosophers). Secondary qualities, by contrast, are not properties of bodies-in-themselves.
Heat was for Galileo the paradigmatic example of a so-called secondary quality. 'Heat' was for Galileo not a "real attribute, property, and quality that truly inheres in the material by which we feel warmed." But, what is the nature of heat then and how is it produced in us? According to the author of the *Discorsi* (1638), secondary qualities such as heat which are "considered to be qualities inherent in external objects, do not really have any existence except in us, and that outside of us they are nothing but names. Now I say that I am inclined to believe that heat is of this kind. The materials which produce heat in us and make us feel it, and which we call by the general name fire, are large collections of tiny corpuscles shaped in such and such manner and moving with such and such a speed; when they meet our body, they penetrate it because of their extremely small size. Their contact, which they make as they pass through our bodily substance and which we feel, is the property we call heat…." Obviously, Galileo's view on heat here bears the influence of atomists such as Epicurus and Lucretius whose work *De Rerum Natura* had been rediscovered in January 1417, and brought to wide public attention by Poggio Bracciolini (Greenblatt 2012) via a medieval copy.

Heat as a motion of parts

Francis Bacon (1561-1626) too defined 'heat' in terms of motion: "Heat itself, its essence and quiddity is motion and nothing else." Later, in 1661, Robert Boyle stated in his definition of Mechanical Philosophy (or Corpuscular Philosophy), which he included in the preface of his *Physiological Essays* (1661), that all natural phenomena had to be explained by means of two general principles: motion and matter. Consequently, very basically, there is no heat in nature. There is only matter and motion. Boyle's definition expressed very well how most of his contemporaries thought about qualities such as heat. Generally speaking, atomists as well as Cartesians explained "heat" in terms of the motion of tiny corpuscles. Robert Hooke for instance, wrote: "Heat being nothing else but a brisk and vehement agitation of the parts of a body." We find similar ideas in Descartes, Spinoza, Locke and other early modern philosophers.

Qualitative and quantitative measurement of heat

For the Ancients and Scholastics, heat was considered to be a manifest quality opposed to the contrary quality cold and linked to one of the five elements, namely fire. For Galileo, by contrast, heat is an affection which entails interaction. However, an affection is subjective. Indeed, person A can experience something as being hot while at the same time person B feels it to be cold. How can this problem of subjectivity be overcome? Galileo addressed this problem. Instead of using the affection of a human body in order to study the presence of heat, the Italian physicist used a gas tube (Mach 2013). By observing the effect that an affecting body had on the volume of air in the tube, he could measure the 'hotness' of the body with which it was in contact in a much more objective way. Moreover, he could compare it with the 'hotness' of other bodies. Galileo's air thermoscope was a first attempt at what later would become a thermometer used for measuring the temperature of a physical object. (Valleriani 2010)

According to several sources (Middleton 1966), Galileo might have invented he thermoscope while he was professor at Padua. However, other sources argue that rather the physiologist and physician Santorio Santorio (1561-1636) had developed the first thermoscope [*thermoscopium*], which he used for medical diagnoses. It is probably more correct, though, to argue that the invention of the thermoscope was the result of scientific activities which took place around 1610 in Padua.

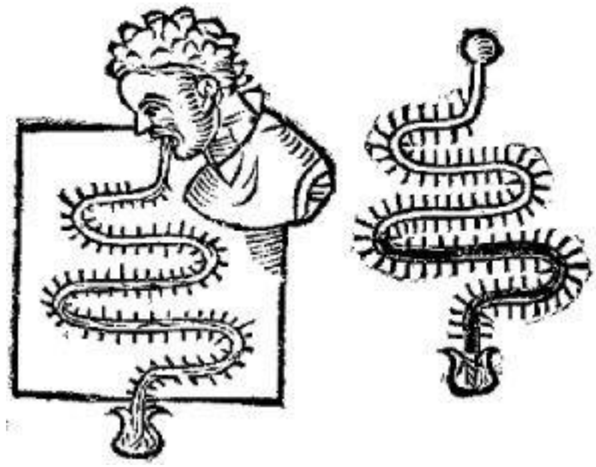

Fig. 1: The Paduan professor and medicine Santorio Santorio adapted his thermometer - which had a scale and a sensor - to his medical practice and used it for measurement of the body temperature of his patients. This illustration is included on page 307-308 of Santorio's *Opera* (1660).

However, it is important to notice that other natural philosophers also developed similar thermoscopes for measuring of heat during the same period. For instance, Giuseppe Biancani (1566-1624) included an illustration of a thermometer in his *Sphaera mundi* (1620). In 1611, there already existed a thermoscope with a scale or a thermometer, designed by Bartolomeo Telioux, which could be used for quantitative instead of qualitive measurements of heat (Chaldecott 1952). And, also Robert Fludd (1574-1637) claimed to have invented the air thermometer. Furthermore, in 17th century numerous authors regarded Cornelis Drebbel (1572-1633) as the inventor of the thermometer.

The newly designed gasthermometer designed by Galileo, Santorio and the other contemporaries that have been mentioned were gasthermometers based on a principle that was known at the time and which goes back to Philo of Byzantium (c.280-220 BC) and Hero of Alexandria (c.10 AD- c.70 AD). Hero's *Pneumatica* which was known by Santorio and by Galileo. It had appeared in Latin translation in 1575 and in Italian translation in 1589. Furthermore, it is likely that Fludd had access to twelfth- or thirteenth century manuscripts of Philo's work (Middleton 1966; Taylor 1942). Obviously, Fludd designed his gasthermometer based on Philo's experiment, as his illustrations make clear.

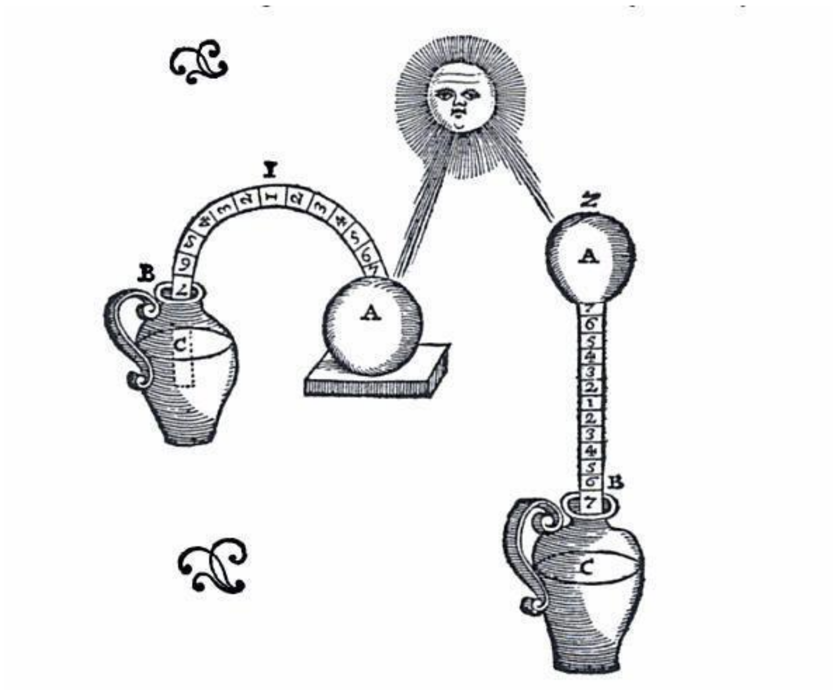

Fig. 2: Fludd’s figure showing on the left Philo’s thermometer and on the right his own thermometer. This illustration is included on the second page of his *Philosophia moysaica* (1638).

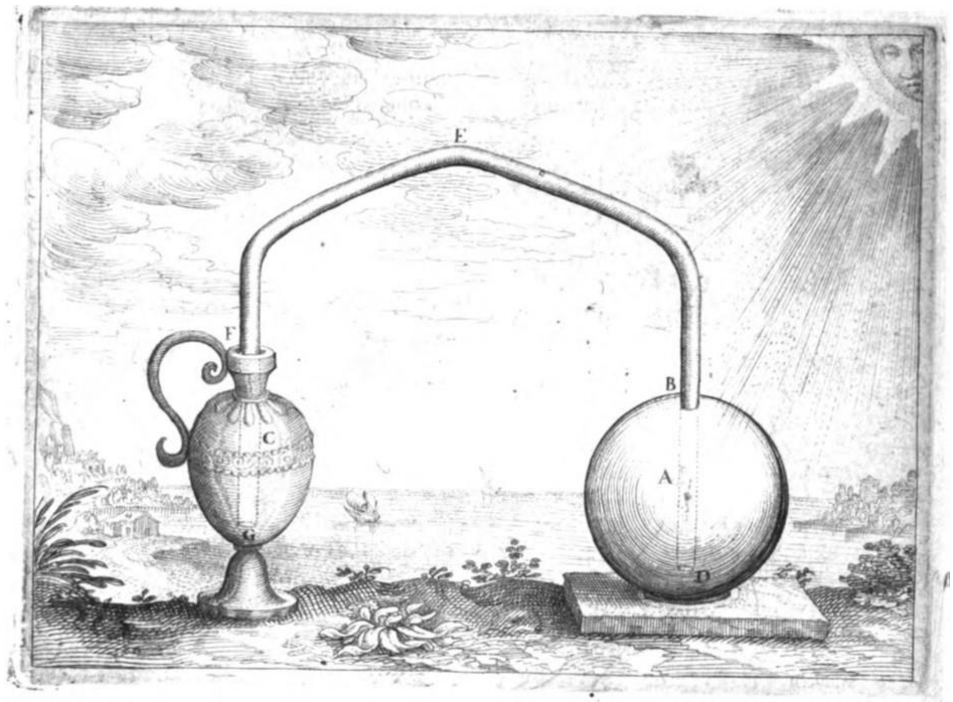

Fig. 3: Fludd’s figure of Philo’s thermometer,which he included on page 204 of the second volume of his *Utriusque* (1617-24).

Joseph Solomon Delmedigo (1591-1655), however, in his *Ma'yan Ganim* (1629) compares the gas thermometer, which he learned about as a student at Padua, with another type of thermometer which is closer to the kind thermometer which we use today: the liquid-in-glass thermometer (Adler 1997). This thermometer was provided with a scale and was designed on the basis of a different principle than Philo's gas thermometer. Interestingly, Galileo's ex-student described this type of thermometer in a text probably written as early as 1621 and published in 1629, even adding an illustration of this type of thermometer. This is more than 30 years before the sealed thermometer designed by Ferdinand II, Grand Duke of Tuscany, who is often credited with the invention of this type of thermometer. (Adler 1997).

Cross-References

Atomism in renaissance
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Fludd, Robert
Galenus, Claudius
Galileo, Galilei
Harvey, William
Life
Innate heat
Sanctorius
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