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## Robert Boyle's Experiments on Cold: A Study of the Role of Chemical Experiments

Christiana Christopoulou\*

Cold was one of the few qualities of matter which formed part of Boyle's<sup>1</sup> early experimental agenda at the beginning of his experimental activities in 1649.<sup>2</sup> Boyle had initiated his experimental studies with experiments of chemical, alchemical and pharmaceutical interest. During this early period of experimentation he also designed schemes to investigate other qualities of matter such as heat, fluidity, firmness, porosity and colour which he developed in parallel with his first ideas on atomism and the composition of matter. During the first half of the 1660's, Boyle published *The Sceptical Chymist*<sup>3</sup> (1661) and the essay 'Essay on Nitre'.<sup>4</sup> In the first, he presented experiments on the analysis of bodies through chemical processes, with which he attempted to refute the predominant theories on the constitution of matter. In the second, experiments on the analysis and composition of nitre were used to support his views on the corpuscular structure of matter. During the same period, Boyle published two treatises on qualities of matter which he considered the most comprehensive in their subject, *The History of Fluidity and Firmness* (1662)<sup>5</sup> and *New Experiments and Observations Touching Cold or an Experimental History of Cold, Begun* (1665)<sup>6</sup> (which from here is referred to as *Cold*). In this paper some of the categories of experiments presented in the treatise *Cold*<sup>7</sup> will be used in a case study to examine the role of chemical and alchemical practices as well as the knowledge produced by them, in the development of certain experimental inquiries and experimental practices on cold. Firstly, it will be illustrated how the phenomena of cold and particularly the process of freezing were shown by Boyle to provide new ways of separating substances and of producing knowledge on the chemical qualities of bodies and the classification of various substances. Secondly, it will be shown that knowledge on the categories of substances produced through the use of chemical processes played an important role in the formation of certain experimental inquiries on cold. Thirdly, it will be argued that some of the experimental issues treated in *Cold* supported and corroborated Boyle's arguments against the chemical theories

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\* Department of the History and Philosophy of Science, University of Athens. Home-address: 2 Doras D'Istrias St., 10676, Athens, Greece. [christiana\\_christopoulou@hotmail.com](mailto:christiana_christopoulou@hotmail.com)

of the constitution of matter as treated in the *Sceptical Chymist*. It will be suggested that Boyle's experimental examination of the quality of cold constituted an effort to form a new experimental field in which chemical and alchemical practices played an important role.

### Experimental History of Cold, Begun

Boyle's treatise on *Cold* was structured after the Baconian principles of a "history". Boyle claimed to be presenting experimental results and observations on phenomena of cold without engaging into a discussion of a theory for the explanation of the nature of cold,<sup>8</sup> nevertheless, *Cold* was not a pure Baconian history. In various investigations, his trials focused on the refutation of predominant theories of his time such as the Aristotelian theory of the four principles of matter and Pierre Gassendi's (1592-1655) theory on the existence of "frigorific corpuscles" of cold. *Cold* consists of a vast range of experimental trials that can be categorised in five general thematic groups. The first and largest group contains experiments on the phenomena of freezing. Central to Boyle's experimental scheme on cold was the examination of the ability of certain categories of liquids and solid bodies to freeze, and the various aspects of the expansion of freezing water and certain related liquids. The verification of the expansion of water by freezing had opened up new experimental themes, such as the measurement of its expansion, the investigation of the expansive force of freezing, and the examination of the content of bubbles produced in ice. In the second group of trials Boyle examined the phenomena related to ice such as the cohesion of its parts and its duration in various liquids and in the air. In the third group, Boyle examined various degrees of cold by the use of a liquid thermoscope [In the secondary bibliography on the history of the thermometer, the term "thermoscope" is used to signify an instrument that indicates changes in temperature but does not have a standard scale]<sup>9</sup>. He tried to establish the difference between a degree of cold capable to freeze water and that produced by the freezing mixture of salt and snow, as well as the difference between a freezing degree of cold and a lower degree which was unable to cause freezing. The fourth group contained experiments on the ability of cold to diffuse and its transmission through various mediums. In the fifth group of trials Boyle examined those bodies that could either, alone or when mixed with ice or snow, propagate and intensify the quality of cold. The most important trials and observations presented here were aimed at the refutation of the various theories that argued for the existence of a single body which was the primary cause of cold in all other bodies.

A close study of the questions posed and the phenomena examined in the treatise *Cold* shows that part of Boyle's experimental inquiries were developed on the basis of his efforts to refute phenomena and explanations established on Aristotelian and Scholastic principles. The diversity of the phenomena examined as well as thematic categories such as the degrees of cold showed that Boyle was also relying on the Baconian rules of investigating the nature of qualities as presented in the *Novum Organum* (1620)<sup>10</sup> in the form of the three tables of inquiry into the quality of heat. Moreover, some of his trials stemmed from the examination of certain "traditions" on the effects of cold supported by the "chymists"<sup>11</sup> of his time and others contributing to common belief. Boyle had collected the description of phenomena and the explanations of the nature of cold predominant in his time and had converted them into specific inquiries. In contemplating the existing traditions and opinions he had also developed new inquiries into phenomena of cold which allow us to argue that the experimental scheme on cold was opening new pathways to the examination of the quality of cold. Furthermore, the treatise on *Cold* was unique in its time, in terms of its focus on the experimental examination of the phenomena and effects of the quality of cold. Until then, the quality of cold was mainly treated as part of a general theory of matter which was used to explain the qualities of bodies such as heat, cold, fluidity, firmness and others as well as part of the treatment of meteorological phenomena. Some examples are the original Aristotelian works,<sup>12</sup> the scholastic treatises on phenomena of freezing discussed by Aristotle,<sup>13</sup> and the treatises presenting the new atomic and corpuscular theories of matter.<sup>14</sup> The topic of cold was also discussed as part of the observations contained in the writings of navigator's travels to "gelid"[very cold] climates as well as in laymans' books on meteorological observations. It cannot be denied that the examination of cold formed part of Boyle's scheme to construct a corpuscular theory of matter supported by experimental phenomena. Nevertheless, it is evident by the structure and the content of the treatise that at the same time he was trying to form an experimental inquiry that focused primarily on the phenomena, it also considered some questions not directly aiming to support a corpuscular theory of matter.

There are three examples that illustrate the way chemical practices and the knowledge acquired through them was used in the treatise, *Cold*. The first shows the use of cold as a process of chemical separation instead of distillation. The second illustrates the role played by the categories of substances according to their chemical qualities in the examination of the phenomena of freezing and the contribution of experiments on freezing to the classification of substances. The third example, presents how the experiments on cold supported the argument put forward in the *Sceptical Chymist* against the explanation of the qualities of bodies

on the basis of the Aristotelian elementary theory, and the three Paracelcian, or chemical, principles.

On the basis of his experiments on the capacity of various categories of liquids to freeze, such as salts, spirits, oils and various kinds of solutions and *lixiviums*, Boyle was led to the conclusion that only liquids and bodies that contained aqueous and phlegmatic parts could be frozen.<sup>15</sup> According to Boyle only the bodies that properly froze were expanded by the effect of cold. In the cases of frozen spirituous liquids, such as beer as also saline liquids such as seawater it was observed, particularly in “gelid” climates, that the aqueous or phlegmatic part was separated from the spirituous or saline parts by being frozen, whereas the latter remained fluid.<sup>16</sup> Furthermore, in the case of seawater it was observed that once the ice was melted it produced water fresh to the taste. In the *Sceptical Chymist* Boyle had used such observations in order to prove that cold did not have the effect to congregate homogeneous and heterogeneous bodies as was held by the Aristotelian theory.<sup>17</sup> Whereas in the *Sceptical Chymist* Boyle held reservations on reproducing the effects of analysis by freezing in the climate of England, as most of his observations stemmed from phenomena in the “gelid” climates, in the treatise of *Cold* he presented a series of phenomena which showed that he had managed to reproduce some separations as those of beer and solutions of salt in water. Boyle argued that the specific phenomenon caused by cold could be used as a process replacing distillation for practical purposes, in the case of sea and salt water, the separation of water from salt through freezing could be more cost-efficient than the use of heat. The process of freezing was also used to reveal two other important characteristics of the constituents of certain bodies. Firstly, Boyle used the expansion of aqueous liquids as a method to define the proportion of phlegm in them.<sup>18</sup> Secondly, he argued that the process of freezing in solids such as vegetables and fruits revealed the juicy and aqueous parts contained in them which were in some cases invisible.<sup>19</sup> On the basis of this observation and the already verified phenomenon of the expansion of aqueous liquids by freezing,<sup>20</sup> Boyle formed an explanation of the destruction of their texture after being frozen. He proposed that the juicy parts, being expanded by freezing would push hard against the cavities of the solid bodies that contained them, and thus would destroy its texture, in the same way as a fruit gets bruised and rots. Cold could be used to replace in some cases some chemical processes, such as distillations and it could be used also in order to investigate some characteristics of matter.

The experimental inquiries on the ability of liquids and bodies to freeze,<sup>21</sup> their ability to propagate the degree of cold produced by ice and snow,<sup>22</sup> and the examination of the duration of ice in various liquids,<sup>23</sup> were all focused primarily on



categories of liquids and bodies and their chemically produced solutions, distillates, decoctions, and *lixiviums*. In particular, Boyle examined groups of liquids, such as salts, oils, and spirits and used his results to deduce general conclusions on each category of bodies. According to Boyle, solutions of salts, spirits of gross salts as well as other aqueous liquids such as beer, milk, vinegar could be frozen whereas chemical oils and fermented liquids and strong spirits could not. The ability to freeze was related to the amount of aqueous and phlegmatic parts in the liquids. Those that could not freeze were shown to contract by a high degree of cold. Boyle also examined whether the ability to freeze applied to all kinds of liquids belonging to the same category and whether it was preserved when they were processed together to produce a solution. He also examined the differences in the degree of cold and time interval required for the liquids of the same category to freeze or condense. In the case of the experiments on the ability of various chemically processed liquids to intensify the freezing effect of ice and snow, Boyle focused on the examination of the various salts in order to examine whether the effect could be attributed to the saline part. He also examined liquids that varied in acidity. In each trial attention was given to the intensity of the freezing effect which was used as evidence of the degree of cold produced. The ability of a liquid to cause freezing by its mixture with snow was related to its ability to melt the snow more rapidly than it would in its pure form. This characteristic varied even among liquids of the same category. Moreover, Boyle examined whether liquids that were shown to intensify the freezing effect of ice would retain this characteristic after their mixture with other liquids.

The above experiments had multiple purposes. Firstly, they led Boyle to important conclusions on the identification of those parts of liquids responsible for their freezing. Their practical use, in chemical experimentation and in constructing explanations in various phenomena, as for example, the corruption of the texture of alimentary bodies by freezing were discussed earlier. Secondly, the attribution of the ability to freeze or be frozen to certain liquids were used by Boyle to support his views on the classification of certain substances which differed, at least in some cases, to that of physicians and chemists.<sup>24</sup> Thirdly, the experimental results contributed to the examination of the nature of cold. Defining whether the ability to freeze and be frozen was a characteristic attribute of one or multiple substances could be used in Boyle's effort to refute hypotheses like the one held by Gassendi on the nature of nitre. Boyle had executed a wide number of experiments to show that nitre and its products could not be considered the primary cause of cold.<sup>25</sup> He argued that Gassendi's experiments aiming to show that cold was produced in bodies through the participation of nitre were based on experimentation by some chemists of his time who attributed to nitre the capacity to

cause cold on its own without being mixed with snow.

One of the central issues dealt with in the treatise on cold concerns the general view held on various theories of matter, according to which cold can be attributed primarily to an elemental body, by the participation of which it is transmitted to all other bodies.<sup>26</sup> Boyle used experiments and observations from “gelid” climates to refute four hypotheses on the nature of such a body. Aristotelians and scholastic philosophers proposed water, the philosopher of the Hellenistic period, Plutarch suggested earth, the Stoics suggested air and Gassendi suggested nitre. Boyle showed that none of the four bodies could be considered to cause and accept the effects of cold in a more intense degree than the others. Nitre was the only case where he argued using his own experimental results. Boyle showed that although nitre had a freezing effect when mixed with snow, there were other substances that caused more intense effects. Boyle’s arguments against the other three elemental bodies were based on the macroscopic phenomena of freezing in the sea, on earth and its subterranean areas and the atmospheric air. Boyle explained that his argument against the attribution of cold as a primary quality to a single body, was based on his more general belief that such a body does not exist. He pointed to the *Sceptical Chymist* where he had attempted to refute the attribution of the cause of the qualities of bodies, such as odours, colours, and gravity, to the four elements by the Aristotelians and to the three or five principles, tenets of “chymical” theories.<sup>27</sup> Boyle’s arguments in *Cold* was presented as corroborating the arguments put forth in the *Sceptical Chymist* against the existence of primary forms in certain substances considered elemental to matter. Experimental results pertaining to a treatise against various tenets of “chymical” theories seemed to work, hand in hand, with experiments on cold, particularly those that treated the macroscopic effects of the quality of cold.

## Conclusions

It has been argued that in setting up his experimental agenda on cold Boyle collected the various established phenomena and theoretical hypotheses on the nature of the quality that had been presented by the, still predominant, Aristotelian Theory, the emerging atomic theories of matter and various treatises on the meteorological and geological phenomena of cold in “gelid” climates. Boyle, guided by his own evolving ideas on the corpuscular theory of matter and explanation of its qualities, structured and organised a set of inquiries on cold that provided not only refutations to the established theories on cold but also initiated new investigations that could possibly lead to new explanatory hypotheses.

The discussion of the experiments performed on the ability of bodies to freeze and be frozen shows that knowledge produced by chemical practices about the categories of substances as well as Boyle's interest in chemical analysis as an investigative tool played an important role in the formation of the particular set of questions. It has also been shown that experiments on freezing produced knowledge useful to the practise of classification of substances according to their "chemical qualities". Moreover the use of freezing as a tool to separate bodies and investigate their constitutive parts was based on important conclusions on the characteristics of freezing as was for instance the expansion of aqueous liquids during the process and the separation of their parts. Therefore, we can argue that there was close collaboration of the knowledge produced by chemical practises and experiments on cold, what seemed for the time a natural philosophical topic. Furthermore it is made evident that the attempt to refute the attribution of the cause of cold to elemental bodies as primary agents of cold, as well as Boyle's general aim to refute the Aristotelian theory of the four elements and the chemical theories of three or five principles, created a context where results from both the experimental practice of cold and the chemical practises were used for a common purpose.

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## Notes

<sup>1</sup> Robert Boyle (1627-1691)-

<sup>2</sup> Boyle's list of unpublished writings: Robert Boyle, "Materialls & Addenda Desing'd towards the Structure & Compleating of Treatises already begun or written. January the 25<sup>th</sup> 1649/1650," in *Works of Robert Boyle*, eds Michael Hunter, Edward Davis, (London: Pickering and Chatto Publishers, 1999-2000), vol.14, 329.

<sup>3</sup> Boyle, *Works of Robert Boyle*, vol. 2, 205-378.

<sup>4</sup> Short title for "A Physico-Chymical Essay, containing an Experiment with some Considerations touching the differing Parts and Redintegration of Salt-Petre," published in the treatise *Certain Physiological Essays*, (1661). Boyle, *Works of Robert Boyle*, vol. 2, 93-113.

<sup>5</sup> One of the five essays published in *Certain Physiological Essays* (1661). Boyle, *Works of Robert Boyle*, vol. 2, 117-203.

<sup>6</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 203-575.

<sup>7</sup> Some studies on Boyle's experimental treatise on cold E. Williams, "Some Experiments on the Expansive Force of Freezing Water," *Annals of Science* 10 (1954): 166-171; Marie B. Hall, "What happened to the Latin Edition of Boyle's *History of Cold*?" *Notes and Records of the Royal Society of London* 17 (1962): 32-35, Muriel A. Bentham, "Some Seventeenth Century Views concerning the Nature of Heat and Cold," *Annals of Science* 2, issue 4, (1937): 431-450 on 445-450; Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England* (Chicago/London: Chicago University Press, 1994), 243-266.

<sup>8</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 221.

<sup>9</sup> Knowles W.E. Middleton, *History of the Thermometer and its uses in Meteorology*, (Baltimore/Maryland: The Johns Hopkins Press, 1966), 4.

<sup>10</sup> Francis Bacon, *The New Organon*, ed. Fulton H. Anderson (Indianapolis: The Library of Liberal Arts/Bobbs-Merrill Educational Publishing, 1960).

<sup>11</sup> For the use of the term "chymists" see Lawrence Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (New Jersey: Princeton Press, 1998), 30-35.

<sup>12</sup> *Meteorology* for instance.

<sup>13</sup> One of the treatises Boyle discussed was Claude De Berigard's (1578-1663) *Circulus Pisanus*.

<sup>14</sup> For instance Descartes' *Meteorology* (1637) and *Principles of Philosophy* (1644), Gassendi's *Animadversiones in decimum Librum Diogeniis Laertiis* (1649) and *Syntagma Philosophicum* (1658) in *Opera Omnia* and Walter Charleton's *Physiologia Epicuro-Gassendo-Charltoniana* (1654).

<sup>15</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 275.

<sup>16</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 443-444.

<sup>17</sup> Boyle, *Sceptical Chymist* in Boyle, *Works of Robert Boyle*, vol. 2, 251-253.

<sup>18</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 324.

<sup>19</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 446-447.

<sup>20</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 301-305.

<sup>21</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 273-275, 275-278.

<sup>22</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 265-273.

<sup>23</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 357-360.

<sup>24</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 269.

<sup>25</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 376-381.

<sup>26</sup> Boyle, *Cold* in Boyle, *Works of Robert Boyle*, vol. 4, 364-381.

<sup>27</sup> Boyle, *Sceptical Chymist* in Boyle, *Works of Robert Boyle*, vol. 2, 330-331, 336-339.

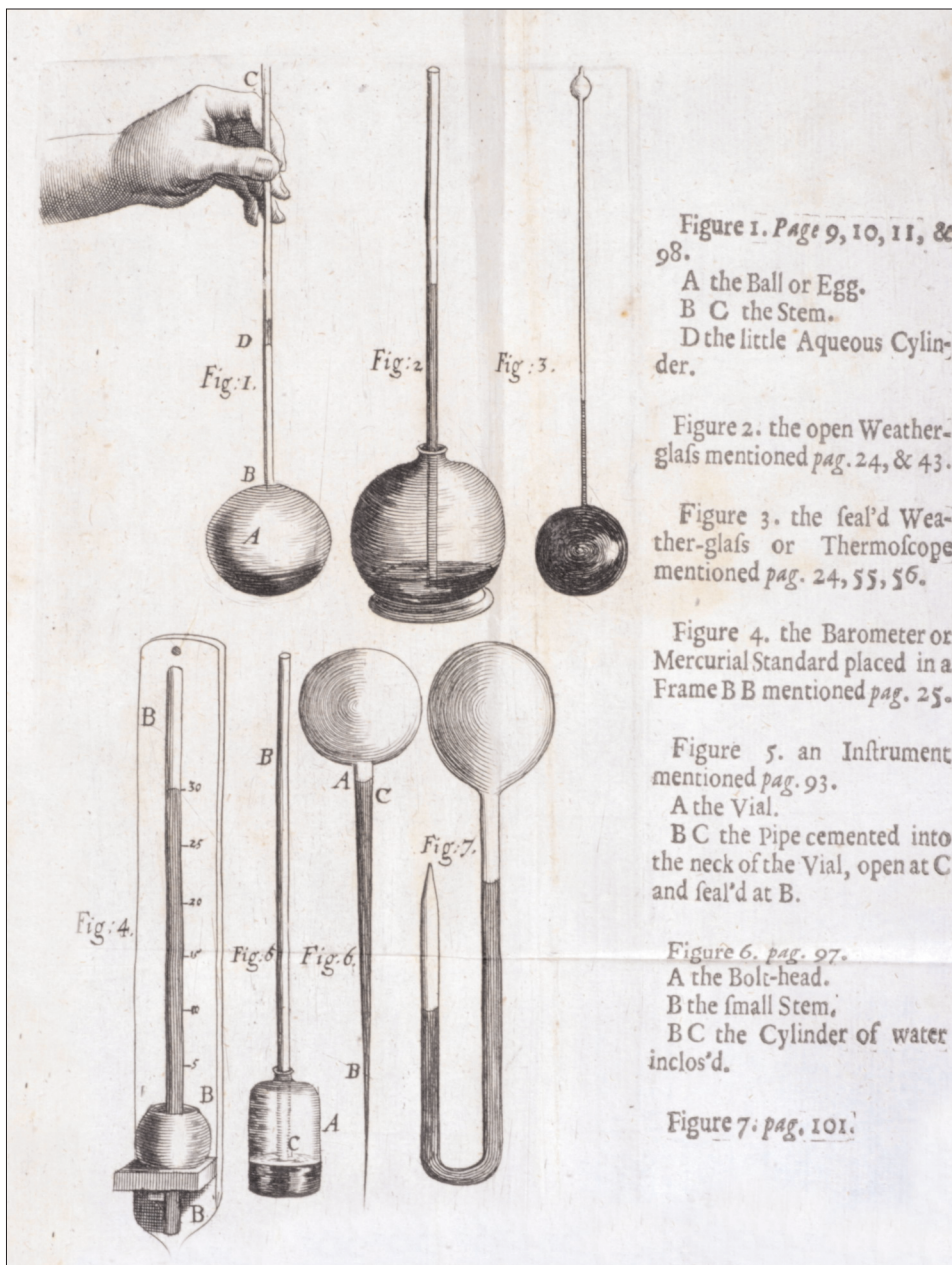


Figure 1. The liquid sealed thermoscope depicted in "Fig. 3" of the 1683 edition of Boyle's *Cold*, Photos by Douglas A. Lockard. Roy G. Neville Historical Chemical Library, Chemical Heritage Foundation, Philadelphia, PA.