Alice in the Land of Cold¹

From Hellfire to the Coldest Spot: An Introductory Note

Cold in western culture has had a rather idiosyncratic presence: from the toilsome transportation of Alpine ice in ancient times to the villas and palaces all the way to Rome (so that the chosen few would enjoy their wine chilled) to the systematic research by the doyen of experimentalists, Robert Boyle, on the nature of cold in the seventeenth century, to the liquefaction of gases in the eighteenth century, to the creation of the “coldest spot on earth” in Leiden in 1908, to the counterintuitive properties of helium at these very low temperatures, to the large scale production of liquid gases for medical and other needs, to the generalized practice of freezing foodstuffs, to the indispensable home refrigerator – in brief: the production and consumption of artificial cold has left deep imprints on an amazing number of scientific and technological developments and has raised fundamental issues in economics, sociology and anthropology.²

Perhaps the most intriguing presence of cold is found in one of the defining texts of western culture, namely Dante Alighieri's *La Divina Commedia*. In *Inferno* it is not so much the deathly heat of flames that do the eternal punishing. Against all “expectations”, Satan is portrayed in many illustrations as a giant beast, half of his body immersed in ice at the center of Hell, as in Gustave Doré's famous xylograph version made around 1860. ➤ **fig. 1** Satan beats his wings, and the cold wind is a continuous reminder that there is not an instant of reprieve for the sinners.

For a public less familiar with Dante there would be another person to incite their imagination, Walt Disney. The myth about the presumed freezing of his body kindled expectations that the creator of immortal genre figures would himself be reborn at a “later date”! Ample supply of liquid nitrogen and some technical issues in the freezing process itself were sufficient to do the trick for anyone.

Cold and Culture: A History of Artificial Cooling

The history of artificial cold is a history in cultural re-articulations, theoretical re-conceptualizations and social re-alignments. It is, thus, a topic for history of science and technology, for science policy studies, for business history, for sociology, for cultural anthropology, for cultural studies, for consumption studies, for home economics and for

1 It is purported that Lawrence Bragg referred to the strange properties of liquid helium and the disorderly world they portrayed as “Alice in Wonderland”.

2 For a historical overview see Russell J. Donnelly, Arthur W. Francis (ed.): *Cryogenic Science and Technology*. Contributions by Leo I. Dana, New York 1985; Anne C. van Helden: *The coldest spot on earth. Kamerlingh Onnes and low temperature research, 1882–1923*, Leiden 1989; Kostas Gavroglu (ed.): *History of Artificial Cold: Scientific, technological and cultural issues*, Dordrecht 2014. The author had the benefit of receiving helpful comments by Matthias Bruhn and sincerely wishes to thank him.

gender studies. From the phenomena of the ultra-cold to the activities utilizing what could be done with the moderately cool, artificial cold, especially during the twentieth century, defined the new discipline of low temperature physics, played a dominant role in the discourse of home economics, and formed new ways of life.

The physical phenomena in temperatures approaching absolute zero were incomprehensible to those immersed in classical physics. The region of the very cold provided a rather novel frame of reference that facilitated the understanding of a reality which could be probed only through quantum mechanics. During the unravelling of the new phenomena and the attempts to understand them, the explanatory possibilities of quantum mechanics were expanded. But a vast range of possibilities were, also, provided by the large-scale production of cold as well. Its use in the preparation and treatment of foodstuffs has, perhaps, been a development whose significance may have been assessed in terms of the quantities involved, but has not been widely studied in the ways of the deep changes it brought to the everyday.

The management of cold re-configured the management of time, and changes in the management of time brought deep changes to culture. It immensely shortened the time people spent for buying food and, eventually, in preparing food by defrosting meals in the micro-ovens. Its overall effects could perhaps be compared with the way spices reconfigured many of the everyday habits and long cherished tastes. The large-scale production and consumption of cold forced the re-appropriation of such notions and practices that were thought to be invariant over the years: freshness, nutritive values and the procurement of commodities were some of them.

In consequence, also a number of hygienic rules had to be re-defined. New tastes – not necessarily “good” or “bad”, but new nevertheless – were acquired. Ever larger segments of the population had to “harmonize” their habits with a new kind of commodity: the frozen version of what they had been buying so far. People started to shop differently, planned meals differently and, perhaps most significantly, cooked differently. The character of a frozen product and its relation to the non-frozen state is not a merely theoretical problem but a very practical one, since it refers to a general perception and the ways that frozen food has been incorporated in the practices of society at large.³

Popularization and quasi-educational processes in the legitimation of the many uses of cooling and refrigerating, and especially those for the preservation and consumption of foodstuff, became an indispensable aspect of the technological framework

3 Gabriella M. Petrick: *The arbiters of taste: producers, consumers, and the industrialization of taste in America, 1900–1960*, Doctoral dissertation, University of Delaware 2006.

1: Gustave Doré: Illustration for Dante's "Inferno" (Chapter 34, v. 20f.), ca. 1860, Wood engraving.

for the utilization of artificial cold. Of course, much of this "education" went hand in hand with the propagation of commercial interests or the creation of better conditions for the blooming of new industrial enterprises. Educating people in order to adopt these new practices, meant persuading people to buy and use the new technologies of cold and, hence, find ways to accommodate the presence of cold in their everyday dealings. During the twentieth century the domestic kitchen became a rather dynamic site full of social and political correlations mediated and managed by women and the "kitchen became the stage where social actors performed a domesticity that was articulated in explicitly technical terms."⁴ The domestication of cold redefined a sizable portion of the domestic activities and promoted the image of a modern housewife with lots

⁴ Ruth Oldenziel, Karin Zachmann: Cold war kitchen, Americanization, technology and European users, Cambridge/MA 2009, p. 8. See also Sigfried Giedion: Mechanization Takes Command: A Contribution to Anonymous History, Minnesota 2014 (first published 1948).

of free time in her hands. The domestication of cold, especially through the electric refrigerator, became a central tenet of the ideology of the emancipated woman through the new house-hold appliances.

Another aspect of the history of cold is related to the observation of counter-intuitive phenomena. In the history of science, a theory or a model has always been a useful prerequisite in preparing the experimenters – in helping them to form their mind-set – to observe new and unexpected phenomena. The observation of counter-intuitive phenomena dictates re-conceptualizations –about which there are always conflicting views among the scientists. There are very few instances, if any, in the history of the physical sciences when a newly observed phenomenon defies even a description in terms of the existing theoretical framework. The discovery of superconductivity in 1911 – of the sudden drop to almost zero of the electrical resistance of some metals at liquid helium temperatures of 4 K – was contradicting the very nature of material bodies.⁵ The materiality of conductors implies some kind of resistance to the electric current. Furthermore, the observations of the amazingly peculiar properties of liquid helium in the late 1920s and the 1930s were contradicting the very nature of liquidity. Liquidity is almost synonymous with viscosity, yet the measurement of viscosity of liquid helium by two different yet legitimate uses for the measurement of viscosity, gave vastly differing results. Superconductivity and superfluidity turned out to be pure and rather unique quantum phenomena and brought on a thoroughly new realization about quantum mechanics – the realization that quantum theory could, indeed, accommodate macroscopic phenomena.

Observing the Phenomena of the Ultra-Cold

The history of cold is full of observational oddities. It would be rather challenging to try to trace the history of cold through these “unexpected and surprising” observations, so the following paragraphs are to list the most apparent ones, in order to outline the epistemic relevance of research concerning artificial cold.

1. The priority disputes in the liquefaction of oxygen: is it “droplets” or “foam”? Starting after the second half of the nineteenth century, there was a rather pronounced activity for liquefying gases. The physics behind the techniques were rather straightforward: releasing gases under pressure lowered their temperature. The required pressures were high, instrumentation had to be

5 Cf. Per Fridtjof Dahl: *Superconductivity: Its historical roots and development from mercury to the ceramic oxides*, New York 1992.

designed so that it would endure the pressures, thermometry should be quite accurate. When oxygen's turn came to be liquefied, a priority dispute arose: was the foam formed at the outlet sufficient evidence for the liquefaction of oxygen, or should there actually be some liquid? Louis Paul Cailletet in Paris and Raoul Pictet in Geneva had both observed oxygen mist in 1877, and it was during 1893–1894 that Karol Olszewski and Zymunt Wróblewski had been able to “actually” observe liquid oxygen in Cracow.

2. After he liquefied hydrogen in 1899, James Dewar at the Royal Institution in London set out to liquefy helium.⁶ Notwithstanding some views that helium cannot be liquefied since at such low temperatures it turns into a metal, Dewar was very confident of his brute force approach: he had mastered the production and further lowering of temperatures, he had invented the flask which bears his name, and nothing – except the shattering of the apparatus that he survived – could stop him from liquefying the last remaining gas: helium. And in fact, he thought he did it. Sending a triumphant telegram on April 6, 1908 to Heike Kamerlingh Onnes he was announcing the liquefaction of helium.⁷ But alas, what he observed were impurities of hydrogen, something that had confused Kamerlingh Onnes himself, when he had also observed the solid pieces which he mistook for solid helium, rather than impurities.
3. On July 10, 1908, Kamerlingh Onnes noted that he could not “see” the liquid helium, until someone shone light from below. For some hours the existence of liquid helium was not noticed, the extreme transparency of the liquid squeezed in a configuration which resembled to babushka dolls, dodged its presence until someone had the idea to shine light from an angle below the surface, so that its presence would be betrayed through the reflection.⁸
4. In 1911, Kamerlingh Onnes observed a most surprising phenomenon: at liquid helium temperatures, the electrical resistance of mercury had a sudden drop to

6 John S. Rowlinson: James Dewar 1842–1923: A ruthless chemist, London 2012.

7 The correspondence between James Dewar and Heike Kamerlingh Onnes is in the *Dewar Papers* at the Royal Institution, London. Also see Dirk van Delft: Freezing physics. Heike Kamerlingh Onnes and the quest for cold, Chicago 2008; Kostas Gavroglu, Yorgos Goudaroulis: Methodological aspects in the development of low temperature physics 1881–1956: Concepts out of context(s), Dordrecht 1989; idem (ed.): Through measurement to knowledge, the selected papers of Heike Kamerlingh Onnes 1853–1926, Dordrecht 1991; Faidra Papanelopoulou: The International Association of Refrigeration through the correspondence of Heike Kamerlingh Onnes and Charles-Edouard Guillaume, 1908–1914. In: *Annals of Science*, 2009, No. 66, pp. 345–370.

8 Cf. article by Lodewijk Johannes Reinders in this issue.

zero. Earlier measurements by James Dewar and John Ambrose Fleming had shown that electrical resistance tended to zero as temperatures were lowered, but they measured an increase at liquid hydrogen temperatures and did not pursue the matter further. It was, furthermore, observed that superconductivity disappeared when the superconductor was surrounded by a magnetic field and one increased its intensity.

5. However, the most decisive and important property of superconductivity was established in 1933. Walther Meissner and Robert Ochsenfeld observed that contrary to the expectations of the physicists and their belief of the previous 20 years, a superconductor expelled the magnetic field after the transition to the superconducting state and the magnetic flux became zero. Superconductors were found to be diamagnetic and, hence, superconductivity a reversible phenomenon. Thermodynamics which were earlier used to explain the phenomenon, but with rather arbitrary assumptions, could now be used justifiably. All this could be visualized by the levitation of a magnet above a superconductor (this is the standard picture of superconductivity in most of the popular and not so popular articles).⁹ In fact, it is precisely this phenomenon which became the “signature” of superconductivity in the subsequent discovery of high temperature superconductors, a property that was both counterintuitive and unexpected. In consequence, the problem to be solved was transformed from a problem in electricity (zero resistance to electrical currents) to a problem in magnetism (dielectric behaviors of metals at very low temperatures).
6. Superfluidity is a phenomenon of liquid helium where deeply seated beliefs about the behavior of liquids took a serious jolt, as superfluidity is comprised by more than one observable property. Below a certain temperature helium has zero viscosity (a liquid with no viscosity is almost a contradiction in terms), it climbs over the edge of its container, if stirred vortices continue to rotate indefinitely. All liquids solidify under their own pressure at low enough temperatures. Helium does not. It can only be solidified under a pressure of 26 atmospheres. The densities and specific heats of all liquids follow a continuous change and increase as the temperature is lowered. Not in the case of helium. These parameters display a maximum at 2.19 K and then decrease. The two methods for measuring the viscosity of any liquid – rotating a disk or forcing a liquid through very small capillaries – give identical results. Not so for liquid

⁹ See the picture tableau, No. 6 on page 116 for an example.

helium below 2 K. When the viscosity of liquid helium is measured with these two methods, the first gives a value that is a million times larger than the second. Finally, all liquids are rather obedient: they can be deposited in open containers, they can be kept in containers with extremely small holes through which they cannot flow and shining light on them does not make them jump. Liquid helium does not tolerate any such constraints. It goes over open containers, leaks through the smallest capillaries, and behaves like a fountain when lit. Liquid helium, below 2.19 K, has the characteristics of a superfluid.

7. For almost 20 years after he had liquefied helium for the first time, and until the end of his life, Kamerlingh Onnes continued to perform all kinds of experiments with “this most exceptional liquid” as he wrote to Dewar a few days after his first success.¹⁰ Might Kamerlingh Onnes have sensed that he was not dealing with a ‘proper’ liquid? This might never be clarified. But even if he felt that there was something peculiar going on, his character, his extreme caution and his commitment to a principle that one can know things only after measurements, most probably held him back from jumping to conclusions in view of certain observations. In his efforts to reach very low temperatures with liquid helium, Kamerlingh Onnes experimented with an arrangement that consisted of a small Dewar vessel in a large one filled with liquid helium. Quite accidentally he observed a transfer, at a striking speed, of liquid helium from one vessel to the other, until the levels in the two containers had reached the same height. He proposed that his observation might be explained by assuming a distillation from one vessel to the other. However, the transfer was actually much too fast to be explained by an ordinary distillation. He briefly described this observation in a report to the Faraday Society in 1922, but no further notice was taken of this remarkable behavior of helium. In 1924, Kamerlingh Onnes and Johan Diederik Anne Boks made more elaborate measurements of the liquid helium density and found that the density-temperature function had a “sharp maximum with a discontinuity of its slope” at that temperature. But despite the fact that Kamerlingh Onnes thought these observations were important, their significance was not appreciated at the time. The analogy with the density maximum in water was tempting enough to exclude other explanations. Nevertheless, the realization that there was a lot more to be learned from helium did originate from these observations.

¹⁰ Kamerlingh Onnes to James Dewar July 20, 1908.

In the following two years, Leo Dana, Arend van Urk and Willem Hendrik Keesom investigated the surface tension, the heat of vaporization and the specific heat of liquid helium. The results of these measurements clearly pointed to a “jump in the value of the surface tension and in the heat of vaporization,” and possibly should indicate “that near the maximum density something happens to helium, which within a small temperature range takes place perhaps even discontinuously [...] The change of density of the liquid also indicates something of the same kind.”

It was in the last year of his life that Kamerlingh Onnes reported the suspected existence of two states of liquid helium, since “they had found values of the specific heat which were so high that they did not dare publish them. They felt sure that something had gone wrong with their measuring equipment.” These experimental measurements led Keesom and Wolfke to propose in 1927 that there might indeed be two kinds of liquid helium: one above 2.3 K, helium I, and one below, helium II. This is a most remarkable paper. Its authors mentioned that they could not observe anything visually, yet they were convinced that there was such a transition. What is also interesting is that the authors, in passing, noted that “from the fact that at lower temperatures the liquid is evidently being moved as easily by the stirrer as at higher temperatures, it also appears that helium II is a very mobile helium.”¹¹

All these observational oddities have led to two reconceptualizations. Superconductivity questioned the very ontology of what a conductor is. By its very definition a conductor, any material “thing” displays resistance. Physicists accommodated the notion of no-resistance in their ways of viewing material entities. Even more dramatic is our reconceptualization of what a fluid is: in analogy with conductors, a fluid cannot be portrayed as something that does not have viscosity. In a way, in classical terms a fluid of zero viscosity is contradiction in terms. Yet, physicists were able to accommodate this new notion of fluid.

11 Donnelly, Francis (see note 2).