# Sample text for

# Absolute zero and the conquest of cold / Tom Shachtman.



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## Chapter 1

### Winter in Summer

King James I of England and Scotland chose a very warm day in the summer of 1620 for Cornelis Drebbel's newest demonstration and decreed that it be held in the Great Hall of Westminster Abbey. Drebbel had promised to delight the king by making the atmosphere of some building cold enough in summer to mimic the dead of winter, and by choosing the Great Hall the king gave him an enormous challenge, the largest interior space in the British Isles, 332 feet from one end to the other and 102 feet from the floor to the golden bosses of its vaulted white ceiling. In 1620 most people considered the likelihood of reversing the seasons inside a building impossible, and many deemed it sacrilege, an attempt to contravene the natural order, to twist the configuration of the world established by God. Early- seven-teenth-century Britons and Europeans construed cold only as a facet of nature in winter. Some believed cold had an origin point, far to the north; the most fanciful maps represented Thule, a near- mythical island thought to exist six days' sailing north of the northern end of Britain and supposedly visited only once, by Pytheas in the fourth century B.C. -- an unexplored, unknown country of permanent cold.

Not until the end of the nineteenth century would a true locus of the cold become a more real destination, as Victorian scientists tried to reach absolute zero, a point they sometimes called "Ultima Thule." Likening themselves to contemporary explorers of the uncharted Arctic and Antarctic regions, these laboratory scientists sought a goal so intense, so horrific, yet so marvelous in its ability to transform all matter that in comparison ice was warm. In the early seventeenth century, even ordinary winter cold was forbidding enough that the imagination failed when trying to grapple with it. "Natural philosophers" could conceive technological feats that would not be accomplished until hundreds of years later -- heavier-than-air flight, ultrarapid ground transportation, the prolongation of life through better medicines, even the construction of skyscrapers and the use of robots -- but not a single human being envisioned a society able to utilize intense cold to advantage. Perhaps this was because while the sources of heat were obvious -- the sun, the crackle of a fire, the life force of animals and human beings -- cold was a mystery without an obvious source, a chill associated with death, inexplicable, too fearsome to investigate. Abhorrence of cold was reflected in only sporadic use made of natural refrigeration, an omission that permitted a large percentage of harvested grains, meats, dairy products, vegetables, fruits, and fish to spoil or rot before humans could eat them. And since natural refrigeration was so underutilized, producing refrigeration by artificial means was considered a preposterous idea. No fabulist in 1620 could conceive that there could ever be a connection between artificial cold and improving the effectiveness of medicine, transportation, or communications, or that mastery of the cold might one day extend the range of humanity over the surface of the earth, the sky, and the sea and increase the comfort and efficiency of human lives. How did water become snow in the heavens or ice on the earth? What formed the snowflakes? Why was ice so slippery? In 1620 these and dozens of other age-old, obvious questions about the cold were considered not only unanswerable but beyond the reach of investigation. Cold could neither be measured, nor described as other than the absence of heat, nor created when it was not already present -- except, perhaps, by a magician.

On that summer day when the king and his party approached Westminster Abbey -- which was in need of some repair, the fabrics torn, the buttresses on the northwest side crumbling in places -- James Stuart was getting on in years, having recently passed his fifty-fourth birthday. In middle age he was still short, broad-shouldered, and barrel- chested, but his hair, once dark, had thinned to a light brown, and the rickets that had affected his growth in youth had lately made his gait more uneven and erratic, requiring him as he walked to lean on a companion's shoulder or arm. He suffered from sudden attacks of abdominal pain, rheumatism, spasms in his limbs, and melancholy. After the loss of his queen, Anne of Denmark, in 1619, he had begun to do uncharacteristic things: even though the king and queen had been estranged and had lived separately for years, James honored Anne in death by siting her sepulcher in Westminster, near the last resting place of his mother, Mary, Queen of Scots. Very few sepulchers or honorary statues decorated the abbey just then.

Summer played havoc with the king's delicate skin, described as "soft as taffeta sarsnet," thin, fragile, and subject to frequent outbreaks of itching and to sweating, which exacerbated the itches. He also suffered from sensitivity to sunlight so severe that undue exposure to the sun overheated him to the point of danger. His susceptibility to heat was worsened by the thick clothing he habitually wore and the doublets specially quilted to resist knife thrusts, an augmentation deemed necessary after several assassination attempts against him. "Look not to find the softness of a down pillow in a crown," the king had written earlier that year, in a small book of meditations on the biblical verse about Jesus crowned with thorns, "but remember that it is a thorny piece of stuff and full of continual cares." Aside from obtaining relief from the heat, James’s interest in the coming demonstration derived from his lifelong obsession with witchcraft and unnatural matters, given fullest flower in his book Demonologie, published in 1597. In 1605, two years after James had ascended to the throne of England upon the death of Queen Elizabeth, his fascination with the occult and his continual search for entertainment led him to accede to an entreaty for patronage by the Dutchman Cornelis Drebbel. James installed Drebbel and his family, with room and board and a grant for expenses, in a suite at Eltham Palace so that Drebbel could set up a laboratory and manufacture, for the particular delight of James's son Henry, such devices as a "perpetual-motion" apparatus, a self-regulating oven, a magic lantern, and a thunder-and-lightning machine. That Drebbel billed himself to James as a magician, not a scientist, shines through in a letter the Dutchman sent home in 1608, regarding his magic- lantern display:

I take my stand in a room and obviously no one is with me. First I change the appearance of my clothing. . . . I am clad first in black velvet, and in a second, as fast as a man can think, I am clad in green velvet, in red velvet, changing myself into all the colors of the world . . . and I present myself as a king, adorned in diamonds, and all sorts of precious stones, and then in a moment become a beggar, all my clothes in rags.

Born at Alkmaar in the north of Holland in 1572 to a landowning family, Cornelis Jacobszoon Drebbel had little formal schooling. For many years he remained unable to read or write in Latin or English, and even after he had taught himself both languages, he continued to despise books and wrote little. In his teens he apprenticed in nearby Haarlem to Hendrik Goltzius, an engraver who dabbled in alchemy, and later married Goltzius's sister. He also evidently learned some technical matters from two Haarlem brothers who later became well known for innovations in mathematics and optics. In 1598 Drebbel was awarded patents for a water-supply system and for a form of self-winding and self-regulating clockworks. In 1604 he published On the Nature of the Elements, a short treatise confabulating alchemy, pious thoughts, and speculation about the interpenetration of the four elements -- earth, fire, air, and water. In 1605 Drebbel wrote to James of England, promising him the greatest invention ever seen, a perpetuum mobile, a perpetual-motion machine, and dedicating to the king the English edition of his book on the elements.

The device Drebbel made at Eltham did not produce perpetual motion, of course, since that is impossible, but according to the contemporary account of Thomas Tymme, a professor of divinity who thought it wondrous, this was a clock with a globe, girdled with a crystal belt in which water was contained, accompanied by various indicators that told the day, month, year, zodiac sign of the month, phases of the moon, and rise and fall of the tides. In Tymme's eyes, Drebbel's machine reflected the perpetual movement of the universe, set in motion by the Creator. Tymme reported in a book that when King James had seemed unwilling to believe in its perpetual motion, Drebbel, that "cunning Bezaleel, in secret manner disclosed to his maiestie the secret, whereupon he applauded the rare invention." Though Tymme said the machine was operated by "a fierie spirit, out of the mineral matter," most likely it was powered either by variations in atmospheric air pressure or by the expansion and contraction of heated and cooled air.

By 1610 the fame of "the philosopher of Alkmaar" had reached the court of Rudolf II, emperor of Bohemia, who invited Drebbel and his family to Prague, where Drebbel would have opportunity to replace the former wizard of the castle, the noted English alchemist Dr. John Dee. Rudolf had earlier lured Danish astronomer Tycho Brahe to the castle at Hradschin, but by this era the emperor had gone beyond such true scientists and was neglecting the affairs of state to work alongside his invited artificers in an effort to find the elusive philosophers' stone, a substance that alchemists believed would transmute base metal into gold. Drebbel's adventure in Prague ended in disaster: Rudolf died in 1612 and his successor imprisoned the Dutchman, either for his loyalty to the wrong faction or for his alleged involvement in a scheme to embezzle money and jewels. Drebbel wrote an impassioned letter to King James in 1613, promising not only a new and improved self-regulating clockwork but also "an instrument by which letters can be read at a distance of an English mile" as well as an elaborate fountain featuring curtains and doors that opened at the touch of the sun, water flowing on cue, and music playing automatically on small frameless keyboards, while "Neptune would appear from a grotto of rocks accompanied by Tritons and sea-goddesses." The king forthwith sent Drebbel instructions to return to England and money for the journey. Drebbel made that fountain for King James, along with a camera obscura and a crude telescope. As time went on, pressure grew on him to continue to produce magically ingenious if not miraculous devices in exchange for his supper, especially after 1618, when circumstances combined to spur James to submit to a new regime of austerity and curb his prodigious household spending.

In 1620 Cornelis Drebbel was forty-eight, and although his beard had turned gray he was still the "fair and handsome man . . . of gentle manners" that a visiting courtier had described years earlier; the Dutch poet and scientist Constantijn Huygens, a recent acquaintance, thought he looked like a "Dutch farmer" but one full of "learned talk . . . reminiscent of the sages of Samos and Sicily." Drebbel's genteel reputation was often contrasted with that of his wife, Sophia, who according to another account spent all of Drebbel's income "on the entertainment of sundry lovers." Huygens's parents warned him against associating with this "magician" and "sorcerer" -- but still asked their son to find out about lens-grinding techniques from him.

At the time of the cold demonstration, according to Drebbel's assistants, the inventor lived "like a philosopher," oblivious to fashion, despising the world and especially its great men, caring for naught but his work, willing to talk only to those who shared his fondness for tobacco, often neglecting to eat because he was lost in scientific thought. These were the circumstances that led him to devise a triumph of man over nature, the reversal of the seasons, the creation of winter in summer. When the king and his followers entered the abbey that summer day, probably through a door beneath the great rose stained-glass window, they were likely ushered to a section near the center, the sacrarium, a relatively narrow and shorter enclosure within the larger hall. There the air was, as Drebbel had promised, quite cool. All would have felt the chill to one degree or another. Guests would have looked askance at certain troughs and other devices they could not fathom, placed near the bases of the walls, and perhaps for guidance up to the white ceiling, partially blackened with soot from the tens of thousands of candles burned in the chamber over the centuries. Shortly, because of James's overheated condition and near-continual sweating, the king began to shiver and he retreated outside, followed by the rest of his party. The demonstration was a success.

How did Drebbel do it? Since he left no written description, and the few accounts of the event are secondhand, answering the question requires some lateral analyses. Years before the incident at Westminster Abbey, the engineer and dramatist Giambattista della Porta had produced ice fantasy gardens, intricate ice sculptures, and iced drinks for Medici banquets in Florence; the excited reports by the nobility about these feats spread through Europe and can be found today in letters and memoirs. Of the more reliable reporters of Drebbels's feat, only Francis Bacon made reference in a 1620 book to "the late experiment of artificiall freezing" at Westminster, so there is a decided lack of detail about the demonstration of mechanical air conditioning, though it was stark evidence that people could exert mastery over a condition of nature. The lack of notice was consistent with a general failure to take Drebbel's remarkable demonstration seriously. To contemporaries, this must have seemed just another piece of magic at a time when the elite of society were struggling to free themselves from a fascination with the more-than- natural that had held the world in thrall for a thousand years. Magic and "natural science" then coexisted uneasily, and it was far from certain that science would eventually prevail. Drebbel's "experiment" may also have failed to attract more attention because of its lack of immediate practical application.

Considerably more astonishment was professed at Drebbel's well-reported 1621 demonstration of a submarine. In three hours the boat traveled "two Dutch miles" underwater on the Thames, from Westminster to Greenwich, in front of the king and thousands of onlookers. None could figure out how the submerged crew of twelve -- plus the inventor himself, who risked drowning along with them -- could continue to breathe in the absence of fresh air. Drebbel provided a clue to the submarine's air supply in his Fifth Element, published that year, which included the cryptic statement that "saltpetre, broken up by the power of fire, was thus changed into something of the nature of the air." Scientific analysis was so rare in 1621 that no one picked up on that clue; decades later British chemist and physicist Robert Boyle would partially comprehend what this demonstration accomplished, writing that "Drebbel conceived that it is not the whole body of the air, but a certain quintessence . . . or spirituous part of it that makes it fit for respiration," and figuring out that when Drebbel observed that the air in the submarine was becoming exhausted, "he would by unstopping a vessel full of his liquor speedily restore [to] the troubled air such a proportion of the vital parts, as would make it again, for a good while, fit for respiration." In short, Drebbel had isolated and discovered oxygen, 150 years before Joseph Priestley. But today Drebbel's name is nowhere associated with that major advance in chemistry.

Drebbel's fondness for the dramatic presentations of the magician rather than the steady progress of the scientist may also help explain, in part, why his preternatural stunt of cooling Westminster in summer produced few reverberations. An inventor and court entertainer, he felt keenly the need to keep the secrets of his demonstrations to himself, a need reflected by his lifelong refusal to document and publish his experiments properly or to keep a diary. "Had Drebbel compiled notebooks describing his undoubted technological works," writes L.

E. Harris, president of a society dedicated to the history of engineering, "he might have attained some lasting fame even without having an influence on future technologies, as is the case with Leonardo da Vinci." In the time-honored way of the magician, Drebbel vouchsafed his "secrets" only in fragments to his apprentices, the voracious Kufflers -- but evidently he did not tell them very much, for after Drebbel's death they were not able to replicate his feats, though they made money from a dye works based on his "secret" formula.

Drebbel appears to have been convinced that if he disclosed the secrets of his work, he would lose the aura of mystery that made him attractive to the king; moreover, by retaining the secrets, he affected to possess a power over nature that in some measure counterbalanced the power of the king over ordinary mortals. But this was only posturing. How dependent Drebbel was became obvious only when King James's death removed his stipend, which reduced him to what Flemish artist Peter Paul Rubens wrote was an "extraordinary" appearance of such shabbiness and disarray that it "fills one with surprise." Drebbel's refusal to reveal his secrets was accepted and sealed by his audience's equal reluctance to demand explanations for marvelous devices and demonstrations. Heinrich van Etten, a contemporary, suggested that audiences found mathematical and scientific puzzles more entertaining if their inner workings were concealed, "for that which doth ravish the spirits is an admirable effect whose cause is unknowne, which if it were discovered, halfe the pleasure is lost." The statement reflects a lack of curiosity that ran throughout society at that time, from the basest peasant to the highest noble. Today we believe curiosity is central to science and perhaps to all of human progress; curiosity is the engine that drives the intellect to seek the causes of things. "Curiosity is one of the permanent and certain characteristics of a vigorous mind," Samuel Johnson would write in 1751, and few could disagree with him.

But in 1620 prevailing opinion disparaged curiosity. The distaste rested on two pillars of ancient thought that resonated throughout the late medieval and Renaissance eras. In the fifth century Saint Augustine had condemned curiosity as a base longing to know the trivial, contrasting it with the elevated pleasures of faith, which he believed provided all the explanations that humankind needed; curiosity was anathema because it meant delving too deeply into what God had created. Adding to the distrust of curiosity and of any quest to unlock the "secrets" of natural phenomena was a belief that investigating nature's hidden workings ran counter to Aristotle's teachings, inscribed nearly a thousand years before Augustine. Aristotle had taught that nature could be entirely apprehended by the senses, that knowledge was not obtainable through experiment and could be derived only as a byproduct of reason and logic. In the thirteenth century, Thomas Aquinas had fused the philosophies of Aristotle and Augustine, as they related to scientific inquiry, and since then his synthesis had been dominant. John Donne, who owed his high ecclesiastical position to King James, vehemently agreed with Aquinas that it was impious to attempt to uncover any hidden truths about nature.

In the early 1600s, however, beliefs that decried curiosity and restricted information about the "secrets" of nature to a handful of cognoscenti were under attack, and the most highly influential English opponent of such views was a man who tried to explain Drebbel's demonstration at Westminster, though he probably had not been present at it: Sir Francis Bacon, Baron Verulam, lord chancellor of England. Lawyer, historian, philosopher, and politician, Bacon more than anyone else in England helped banish magic and secrets by championing science based on experimentation. Constantijn Huygens might write of Drebbel and Bacon in the same sentence and contend that their accomplishments were of equal moment, but they were not colleagues. Rather, they were polar opposites, Drebbel among the last of the magician-artificers and Bacon the first true English scientific thinker. In Drebbel's refusal to explain his stunt and Bacon's insistence on trying to discern its chemical mechanism of cooling lies the deeper significance of Drebbel's demonstration: it symbolized the passing of the era in which magic held all the fascination and the arrival of science at center stage to begin the process of providing explanations of nature that would greatly advance human civilization.

We infer Bacon's absence at the Westminster event because he did not write himself an immediate note about it, as he had done after viewing Drebbel's demonstrations of earlier devices and machines at Eltham Palace. Bacon's appetite for scientific stunts was declining; in 1605, while courting King James, he had condoned the study of marvels, witchcraft, and sorcery "for inquisition of truth, as your majesty has shown in his own example [in Demonologie]," but later Bacon insisted that "experiments of natural magic should be sifted diligently and severely before they are received, especially those . . . commonly derived . . . with great sloth and facility both of believing and inventing."

Another likely reason for Bacon's absence was the gathering storm, fomented by his political enemies, that within a year would result in his abject fall from favor. Shortly after James made Bacon viscount of St. Albans in early 1621, the nobleman was impeached for accepting bribes; after confessing to his guilt, he was stripped of his position and banished from London, though he was spared incarceration. The deeper reason for Bacon's eclipse was related to his growing advocacy of experimental science. English scientist Robert Hooke later identified that reason, in comparing Bacon's treatment to that of Italian scientist Galileo by the Inquisition: "Thus it happened also to . . . Lord Chancellor Bacon, for being too prying into the then receiv'd philosophy."

Bacon was never a man to ignore what another experimenter might turn up that could be relevant to his own studies, and perhaps that is why, in Novum Organum, published later in 1620, he wrote the short section that, according to an associate, tried to fathom "the late experiment of artificiall freezing" at Westminster: "Nitre (or rather its spirit) is very cold, and hence nitre or salt when added to snow or ice intensifies the cold of the latter, the nitre by adding to its own cold, but the salt by supplying activity to the cold of the snow." Nitre, also known as saltpeter, is a common chemical compound (today called potassium nitrate) and the active ingredient of gunpowder. Bacon's guess about Drebbel using nitre was a good one: the court artificer had himself written of saltpeter and was also on intimate terms with Sir Thomas Chaloner, author of a book solely about nitre; moreover, as Bacon hints, many alchemists and would-be scientists had been experimenting with the cold-inducing aspects of nitre and common salt.

A source for those experiments was one of the most popular "books of secrets" of the age, Giambattista della Porta's Natural Magic, first published in Italy in 1558 and enlarged -- as well as translated into virtually every other European language -- in 1589. Della Porta was one of the most famous men in Italy, a friend of German astronomer Johannes Kepler and Galileo, a man so learned in the ways of nature that he was expected at any moment to discover the philosophers' stone. Jailed by the Inquisition for his magic, he continued to write about it. In Natural Magic, following sections treating alchemy, invisible writing, the making of cosmetics, gardening, and the accumulation of household goods, della Porta appended a final miscellany, "The Chaos," in which he mentioned mixing snow and nitre to produce a "mighty cold" that was twice as cold as either substance -- cold enough to make ice.

With these hints, and some technology of the era, we can finally reconstruct how Drebbel probably accomplished his feat.

At an early hour of the morning, Drebbel and his assistants brought into Westminster Abbey long, watertight troughs and broad, low vats and placed them alongside the walls and in the midst of the limited part of the abbey that they planned to cool, most likely that inner, narrow transept near the portal through which the king and courtiers would enter, an area they knew would be in shade most of the day and especially at that hour. They also brought in snow, which would have been available from those among the nobility who had on their estates underground snow pits to keep unmelted snow and ice in storage after the winter, to use for cooling drinks in summer. Drebbel filled the troughs and vats partway with water, the coolest he could find, which he no doubt had fetched directly from the nearby Thames. For several hours, he infused nitre, salt, and snow into the water, creating ice crystals and a mixture whose temperature -- if he could have measured the temperature, which he could not, since no thermometers capable of such accuracy yet existed - - was actually reduced below the freezing point of water, as della Porta had guessed. Some of the troughs were metal, and the freezing mixture chilled the metal, which aided the refrigerating process by keeping the contents of the troughs cold. More to the point of the exercise, the freezing mixture cooled the air directly above the troughs and vats. In Drebbel's Elements treatise he referred to the frequently observed phenomenon of heated air rising, and he seems also to have understood that cool air is heavier than warm air and tends to stay close to the ground. Now he used this principle to generate a mass of cool air that displaced warmer air in the cathedral up in the direction of the capacious ceiling. He did not need to force the warm air to rise very far -- just 10 feet high or so, until it was above the height of the king and courtiers. And he did not need to make the space very cold -- a decrease in temperature from, say, 85º to 65ºF would have proved sufficient to chill an overheated king. This cooling Drebbel accomplished over the course of several hours, perhaps aiding the process by fanning the cool air so that remaining pockets of warm air thoroughly dispersed, before the court party arrived and experienced the shock of the cold.