Please Note: The figures noted in this presentation refer to the PowerPoint slides available through the Interpretive Studies section of the John Snow Archive and Research Companion web site, http://www.matrix.msu.edu/~johnsnow .

1847 – John Snow's *annus mirabilis*, year of consilience

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and

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I thank the Association for honoring our book, Cholera, Chloroform, and the Science of Medicine: A Life of John Snow, with the David M. Little prize last October. I bring you greetings from the rest of the writing team – Howard Brody, Nigel Paneth, Steve Rachman, Mike Rip, and David Zuck. We wrote the manuscript. A team at Oxford University Press transformed it into the book. Your award honors them as well, particularly Jeffrey House, recently retired editor of the Medicine Division, and Nancy Wolitzer, who supervised every facet of the production process. Carrie Pedersen, the new Medicine editor who is in Birmingham for this and the AAHM conferences, will shepherd the book's life from now on.

My presentation this morning has its origins in disagreement within the writing team about how to structure the ether chapter. Four of us, including the primary drafter, Steve Rachman, preferred a thematic format. David Zuck and I believed a narrative would be more effective, but we were outvoted. Six months ago, David and I decided to begin writing such a narrative for publication as an article. When A.J. Wright asked me to deliver the opening plenary lecture, David and I thought it would be appropriate to distill a preparation from the emerging manuscript.

On Monday morning, the 28th of December 1846, John Snow, M.D., was among three medical friends who James Robinson **(Fig. 2)** had invited to his home surgery in Gower Street **(Fig. 3; Fig. 4)**, several blocks south of University College Hospital, central London **(Fig. 5;** circled).[1] The intention was to demonstrate the effectiveness of a new ether inhaler **(Fig. 6)**, constructed according to his specifications by a local medical instrument technician.[2] Robinson poured one ounce of washed ether over a score of small, triangular sponge pieces, made certain that all pieces were moist, and placed them in both the upper and lower parts of his inhaler, based on a Nooth's glass apparatus **(Fig. 7)**, which had been invented in 1776 to make soda water in the home. He inserted a double glass stopper into the opening at the top **(Fig. 8)**, and covered it with a glass cap.[3]

The first patient – "a young man, of robust constitution, and about twenty years of age" – was brought into the room and seated in a chair. Robinson picked up the mouthpiece, connected by a flexible tube to the lower part of the apparatus **(Fig. 9)**, and told the man to clasp his teeth over a protruding ivory tube (arrow) while the pad (green oval), made of sheet copper, leather and wool, was shaped to fit the contours of his lower face. When he was satisfied that no atmospheric air should seep past the pad of the mouthpiece, he removed it long enough to insert a clip over the nostrils **(Fig. 10)**, remove the cap (light green oval) from the top of the apparatus, and the inner stopper (dark green oval), set the stopcock (blue square) in front of the mouthpiece in the open position, and reposition the face-pad. He told the patient to inhale, then on exhalation noted that the horizontal valve (green arrow) popped up as expired air passed into the room; it, as well as the vertical swing valve (red arrow) preventing expired air from returning to the apparatus, were functioning properly. According to Robinson's case note, the "patient, after inhaling the vapour for about two minutes, became insensible, and the tooth was extracted. On recovering, he was requested to give an account of his sensations, but he could neither recollect anything, nor was he aware when his tooth had been taken out; . . . he left the surgery perfectly well."[4]

The next patient, a youth in his late teens, was less compliant. Rumors were already circulating, only a week since Robinson's first use of inhalation ether in Dr. Francis Boott's home (**Fig. 11**), when he had rendered Miss Lonsdale insensible before extracting a molar (**Fig. 12**), that this dentist "'sent people to sleep and then took out the whole of their teeth.'" The lad did not want himself readied for a set of dentures, and he adamantly refused to let Robinson place the mouthpiece on his face. So Snow and his two surgeon colleagues watched as Robinson yanked a rotten tooth the old-fashioned way – similar to the dentist in this painting **(Fig. 13)** by Theodor Rombouts from two centuries earlier.[5]

But Robinson had one more patient waiting in the foyer, a girl "between thirteen and fourteen years of age, of a weakly and delicate constitution." She did not resist the administration of ether vapor, and "in twenty inspirations became perfectly narcotized." Although Robinson was able to remove a diseased molar in seconds, it took the girl four minutes to "recover her faculties"; she immediately "complained of head-ache and oppression." She felt better after drinking a glass of water, to which a drop of ammonia had been added.[6] Since "she could give no account of her state, and was unaware when or how the tooth had been removed," Robinson considered this operation a "most perfect success", even though he had administered "more vapour . . . than necessary."[7]

John Snow's reactions to Robinson's use of ether are unknown. He said nothing publicly about this new anesthetic process for nearly three weeks. Then, on Saturday the 16th of January, 1847, he announced at a meeting of the Westminster Medical Society that he had designed an inhaler that he believed was vastly superior to those currently in use, including Robinson's. What had happened?

* * *

We know which medical journals and newspapers Snow read regularly, so it is very likely that before visiting Robinson's surgery he had seen the December 18 issue of the London Medical Gazette (**Fig. 14**) that announced Morton's "discovery" of a new anodyne process. While the editors noted that "any one may put the new process to the test of experiment," **(Fig. 15)** "some caution must . . . be observed in employing the vapour of ether in the way suggested. Ether is a strong narcotic, and its vapour speedily produces complete lethargy and coma: it is exceedingly volatile . . . . In one case it has destroyed life, and in another caused apoplexy. . . . It must be regarded as producing a state of temporary poisoning in which the nervous system is most powerfully affected."[8] Snow had apparently never used ether "as a mere frolic," following "the old plan of introducing a teaspoonful of ether into a bladder or silk bag, and inhaling it in the same manner as nitrous oxide gas."[9] As a clinician, however, he was quite familiar with ether as a "class of medicines." He knew it could be administered safely because he had undertaken experiments with it and "other volatile medicines" in 1842/43 and recommended their therapeutic value for the relief of respiratory congestion. He also knew that ether did not act like typical poisons since he had determined that it was a gas which, like carbon dioxide, "escape[d] with the breath."[10] So his mind was hardly a blank slate when he had observed Robinson administer ether at the end of December 1846.[11]

During the first ten days of the new year, the medical journals reported inconsistent results from the inhalation of sulphuric ether, so-called because it was prepared by reacting ethyl alcohol with sulphuric acid. New Year's day issues of the London Medical Gazette and the Pharmaceutical Journal described two operations on the 21st of December by Robert Liston, surgeon at University College Hospital, in which both patients were successfully rendered insensible by "an ingenious apparatus . . . contrived by Mr. Squire, of Oxford Street" **(Fig. 16)**.[12] On 2 January, the Lancet published accounts originating from Boston in which patients awoke in the midst of the operation, even after inhaling ether for as long as eight minutes before the procedure began. While there were no reports of any fatalities, there had been cases where the pulse plummeted, or a lethargic state continued for as much as an hour.[13] Under the headline, "painless surgical operations," the January 2nd issue of Medical Times noted that Robinson had tested Morton's "invention" by means of what the editors considered "an elegant apparatus."[14]

The 9 January issue of the Medical Times contained a wood engraving (**Fig. 17**) of Robinson's original inhaler and an effusive editorial endorsement, asserting that it best fulfilled all their requirements for the successful administration of "the ethereal vapour."[15] By then it was already outdated by the new inhaler Robinson had used in Snow's presence. The editors also endorsed the original Robinson inhaler by counter-examples: At University College Hospital eight days earlier, Squire's apparatus **(Fig. 18)** had failed "to produce insensibility" in a patient, while Liston cooled his heels for ten minutes before deciding to amputate "with the usual amount of pain." Squire's apparatus worked no better the following day for a different surgeon, nor again for Liston two days later – even though, this time, he waited twenty minutes. But then "a most extraordinary scene occurred," according to the editorial. In the next operation, "Mr. Robinson superintended the inhalation of the vapour, using his own apparatus; [**(Fig. 19)**] the patient became perfectly insensible in two minutes, and the operation was completed before the patient was aware that it had commenced."[16]

* * *

But Snow **(Fig. 20)** had not jumped on the Robinson bandwagon. During the fortnight after observing the dentist use his second inhaler, Snow had confirmed a suspicion – that the inconsistent results he observed in Robinson's surgery and read about in the medical journals were caused by variations in the temperature of the air passing through glass inhalers such as the modified Nooth's apparatus Robinson was using. Snow had secured a glass vessel, inserted sponges soaked with ether, and using "a delicate thermometer," noted that the air "leaves the apparatus many degrees colder than it entered."[17] As a physician who was also an expert chemist, it is likely that he knew from prior study and experimentation that liquid ether exerted a cooling effect on ambient air and that the elastic force (saturated vapor pressure – SVP) of volatile liquids such as ether was temperature-dependent. He wrote a few months later **(Fig. 21)** that it "occurred to my mind that by regulating the temperature of the air whilst it is exposed to the ether, we should have the means of ascertaining and adjusting the quantity of vapour that will be contained in it" ("IVE," 498). The striking fact is that whereas Robinson and other proto-anesthetists attempted to resolve problems with the new process only by empirical tinkering with their inhalers and mouthpieces, Snow's initial approach was totally different.

He looked to chemistry and physics for verification of his hypothesis that the amount of ether inhaled depended on temperature. He was aware that "the elastic force of the vapour of ether has been investigated by Dalton, and later by Ure" ("IVE," 498). Around 1805, arising from his meteorological studies into rainfall, Dalton had formulated the concept of elastic force. The <u>New System of Chemical Philosophy</u> that he published a few years later contained SVP tables (**Fig. 22**) over a range of temperatures for various volatile liquids, including ether.[18] The physician and pioneer of chemistry, Andrew Ure, recalculated Dalton's tables in a search for greater accuracy, and published his results in an 1818 essay on "Doctrines of Caloric."[19] With respect to ether, Ure proposed a set of ratios (**Fig. 23**) for the elastic force that accorded closely with actual measurements he conducted over mercury, using a manometer of his own devising **(Fig. 24)**.[20]

If Ure's table was accurate, Snow could save himself a lot of work. He bent a long graduated tube until it approximated the form of Ure's instrument **(Fig. 25)** ("IVE," 498-99). Then, he immersed the tube in a tall glass jar containing water at a temperature of 44°F, making certain that the sealed leg was completely covered by the water. He added mercury, passed air into the sealed leg, made certain the mercury was at the same level in both legs, and noted the distance between the level of mercury and the top of the sealed leg (for example, one inch in the graduated tube on the left in the figure). Next, he carefully inserted a long tube into the open leg, withdrew most of the mercury, added a few drops of unwashed sulphuric ether – an accurate choice for replicating Ure's experiments, but it would become an embarrassing oversight later – tipped the jar and instrument a little, and breathed gently through the tube until the ether passed through the mercury and mixed with the air in the sealed leg. Snow righted the instrument, added mercury until the two legs were equilibrated, and re-measured the level in the sealed leg – now 1.370 inches (in the graduated tube on the right in the figure). He then divided the original volume by the new measurement to determine the percentages of air and ether vapor **(Fig. 26)**:

$$1 \div 1.370 = 73\% \text{ air,}$$

with the difference of 27% being the amount of ether vapor at that temperature. Using Dalton's Law of Partial Pressures, a quick calculation: 0.27 x 30 (standard barometric pressure) = 8.1 for the elastic force, which was identical with Ure's figure for 44°F **(Fig. 27).** Successively, Snow repeated this process in 10° increments between 44° and 84°. When these results also agreed with Ure's table, he found that he had confirmed the first part of his hypothesis: the amount of saturated ether vapor in air increased with temperature – doubled, in fact, between 44°F and 74°F.[21] His findings meant that if the ambient temperature of a room was low, glass inhalers yielded very little ether vapor. Then, during the second week of January, Snow used Ure's formula to create a more refined table **(Fig. 28)** of the "strength of ether vapour" in 100 cubic inches of air at two-degree temperature intervals. He added columns on weights for each interval **,** using standard formulas **(Fig. 29)** that 1 cubic inch of ether yields 0.787 grains of liquid ether, and that 1 cubic inch of air weighs 0.30 grains ("IVE," 498). He submitted this table to three medical journals for publication.

Next he began to design an apparatus that would permit him to control the temperature of the air that a patient would inhale. Metals and water were good conductors of heat. The trick was to construct an apparatus using both conductors that permitted an operator to regulate the temperature of ether vapor and air passing though it without obstructing the patient's breathing. It occurred to Snow that an apparatus constructed partially on the principle of the Jeffreys humidifier **(Fig. 30)**, which he had used in his practice since 1842, might meet his expectations ("IVE," 500).[22] His design would replace Jeffreys' saucepan by a round tin box; solder the tin volute to the inside of the lid, and provide an opening in the center for adding ether and attaching a flexible tube leading to the mouthpiece; wind a metal tube, open to the atmosphere at one end, around the box, to warm the air before it enters; and immerse the entire vaporizer in a basin of heated water. Snow brought his ideas to Daniel Ferguson, instrument-maker to St. Bartholomew's Hospital with premises in Giltspur Street, who agreed to construct such an apparatus. It would be ready in a few days.

Meanwhile, the second and third weeks of January were also eventful elsewhere in London. Surgeons at most of the major hospitals had tried the new process for painless operations, and many reported successful outcomes. But there had been failures, too, the most abject occurring on Thursday the 14th at St. George's Hospital, where a "large concourse of spectators" observed three botched attempts. The first patient was sent back to the ward fully conscious, when the ether failed to have any effect; the second patient, thought to be insensible, started bawling when the surgeon applied the knife to a diseased finger; and the third awoke before the surgeon finished sawing off his leg. The reporter for the London Medical Gazette noted, in a laconic understatement, that "the effect on the bystanders was anything but favourable . . . ."[23] There was also considerable buzz about new inhalers on the market. Twelve were presented and discussed on the 13th at the Pharmaceutical Society, including a modified version constructed by Squire **(Fig. 31)** and three that Ferguson had contrived for different surgeons. The weekly issue of the Lancet on Saturday, the 16th of January, featured Hooper's latest apparatus **(Fig. 32)**, based on designs provided by Boott and Robinson.

That evening, "Inhalation of ether" was the main event at the weekly meeting of the Westminster Medical Society, held at **(Fig. 33)** Exeter Hall near the Waterloo Bridge (the location of the Strand Palace Hotel today). The first two speakers gave accounts of what they considered successful uses of ether at Charing Cross Hospital, despite some troubling complications. Snow then rose to his feet and said **(Fig. 34)** that:

the great effect of temperature over the relations of atmospheric air with the vapour of

> ether, had apparently been overlooked in the construction and application of the instruments hitherto used. This circumstance would explain in some measure the variety of the results, and account for some of the failures. The operators did not at present know the quantity of vapour they were exhibiting with the air; it would vary immensely according to the temperature of the apartment, as would be seen by some calculations he had made, and suspended in the room. (**Fig. 35**)

He concluded with a brief overview of the apparatus "which Mr. Ferguson, of Smithfield, was making for him," based **(Fig. 36)** "on the plan of the inhaler of Mr. Jeffreys, with some alterations and additions. The air would meet with no obstruction from having to pass through sponge or ether, and the instrument, which would be of metal, as a good conductor of caloric, would be cheap and portable."[24]

The following week, Ferguson brought Snow the inhaler made to his specifications. Snow tested it once, was satisfied, and informed the Secretary of the Westminster Society that he would be able to show it at the next meeting. The London Medical Gazette for Friday the 22nd published the minutes of the previous meeting, but Snow's elaborate table **(Fig. 37)** of ether vapor at different temperatures had been reduced to five entries (**Fig. 38**). Fortunately, he had submitted the full table to the Medical Times, and it appeared the following day.[25] At 8:00 o'clock that evening, the 23rd, only a few dozen members of the Westminster Medical Society were in attendance when Snow demonstrated his ether inhaler (**Fig. 39**). It was a black, circular tin box about five inches in diameter and nearly three inches tall. A pewter tube, open to the air at one end, was coiled around the box before entering the side; Snow believed at the time it was necessary to warm the air before it entered the ether chamber. Inside the box, Mr. Ferguson had soldered a strip of tin, in widening spirals, to the top; this tin strip reached within a half inch of the bottom of the apparatus, so that liquid ether poured through a pipe in the center of the lid could reach the sides without obstruction. After adding ether, the operator would attach a flexible tube, with an inner diameter of five-eights of an inch, to the central pipe and then place the apparatus in a hand basin containing water heated to the temperature required to produce the desired ether-air mixture. For a mouthpiece **(Fig. 40)**, Snow had decided to use the one designed by Samuel J. Tracy of Bart's, perhaps on Ferguson's recommendation since he had constructed it as well **(Fig. 41)**.[26] The apparatus was ingeniously simple, but would it work in the operating theater?

The proof of the Snow-Ferguson tin pudding occurred during three operations the following Thursday at St. George's Hospital **(Fig. 42)**, Hyde Park Corner, just west of Green Park and Piccadilly. It is unclear if Snow had proposed this trial, or if the hospital governors figured they had little reputation left to lose in asking a local physician with an untested apparatus to administer ether for their skeptical surgeons.[27] The trial was public, with spectators and reporters filling the benches of the amphitheater, and the circumstances were less than ideal. Snow would be administering ether for three different surgeons, who were performing three very different operations on three patients of varying ages and physical conditions.[28] Moreover, his only baseline for deciding how much vapor to administer was one test, in which his apparatus heated to 70° produced a powerful effect in thirty seconds – but he had no idea, as yet, how long it would take his apparatus to produce insensibility.[29] When Snow and the first surgeon, Mr. Cæsar Hawkins, were ready, a nursing sister brought six year old William Daphne into the theater and helped him onto the operating table. Snow had heated the basin of water to 65°, which, according to his table **(Fig. 43)**, should deliver about 44% ether vapor (green shaded rectangle). But the ether supplied by most hospitals was washed, which boiled at 100°, whereas the unwashed ether he had used when confirming Ure's figures boiled at 104°. Unaware that every temperature entry on his table overstated the amount of ether vapor, Snow administered air saturated with no more than 40% ether vapor (red shaded rectangle), which young Daphne inhaled "without objection or difficulty."[30] He was insensible in less than two minutes. Mr. Cæsar Hawkins cut into the shin and began removing dead bone from the interior of the tibia. After a minute, the boy stopped breathing, and his face turned purple. Snow removed the mouthpiece. When Daphne opened his eyes and turned his head, Snow re-applied the mouthpiece for a couple of minutes until Cæsar Hawkins had finished what was normally an "extremely painful" operation. The boy awoke and "was taken away without shedding a tear." Cæsar Hawkins was impressed.[31]

Shortly thereafter, Mr. Cutler was scheduled to amputate the thigh of William Cowen, a groom in his early twenties, who had been injured two months earlier when thrown from a horse. Infection had set in. Snow wanted this patient to inhale approximately 50% ether vapor **(Fig. 44)**, so he increased the water temperature to 70°. Mr. Cutler commenced the operation after two minutes of inhalation. Snow employed the same on/off strategy as in the first operation, but with greater effectiveness. Cowen awoke without stirring or having experienced any pain. Cutler was also impressed, and said so to the assembled spectators. Snow's success continued with the third patient, Francis Lewis, a man of 42 in good health except for a large, fatty tumor over his right scapula. Snow added hot water to the basin until the thermometer registered 75° **(Fig. 45)**; Lewis inhaled the ether vapor for two minutes. Snow nodded to Mr. Tatum, who began to excise the tumor as Snow removed and re-applied the mouthpiece in such a manner that Lewis awoke just as Tatum finished his task. Lewis said he had felt no pain. Tatum made a few comments to the audience, and introduced Snow who explained his modus operandi for the three cases.[32]

* * *

But why did Snow consider temperature the decisive factor? Our view is that he approached the inhalation of ether, as he had done with other problems in medicine, from the perspective of the collateral sciences – in this instance as an experimental chemist. In all likelihood, this orientation began during his apprenticeship in Newcastle **(Fig. 46)**. His master, William Hardcastle, gave him time to study the physical and natural sciences, to extend his facility in mathematics, to complete a semester of basic courses, including chemistry, offered by local medical men, and to walk the wards at the Newcastle Infirmary. At the Hunterian School of Medicine in London **(Fig. 47)**, Snow took two chemistry courses from John Hunter Lane, an Edinburgh trained surgeon and physician, although the regulations required only one.[33] His earliest known experiments in applied chemistry occurred when he was a medical student. At Hunter Lane's suggestion, in 1836 he replicated for the Hunterian school a continental technique of injecting vessels in cadavers with arsenic to clear them of dried blood before adding ink. He repeated the procedure, and became ill, the following summer when the weather was "very hot." Some time later, Snow conducted a bio-chemical experiment to replicate the decomposition process. He isolated metallic arsenic from the emitted gases, and later published his findings in the <u>Lancet</u> **(Fig. 48)**, his first publication in a medical journal.[34] At the time, he lived on Frith Street **(Fig. 49)**, a short if circuitous walking distance from where he had lodged as a medical student **(Fig. 50)**. In the fall of 1837, when the Westminster Medical Society debated whether to formally condemn the manufacture and sale of stearin candles containing arsenic, a Select Committee conducted experiments on birds, rabbits, and guinea pigs. When the Committee reported mixed results, Snow, who "had succeeded in detecting arsenious acid in these lights," was dissatisfied. In a suggestive prelude to his criticism during the early weeks of inhalation ether a decade later, Snow repeated the animal experiments at different temperatures because he believed that the Select Committee had erred in relying on the ambient temperature in the room, which varied widely over several days.[35]

After qualifying as a surgeon-apothecary in 1838, Snow continued to demonstrate a lively interest in possible chemical explanations for the medical and public health problems of his time. For example, the Westminster Society became quite exercised in 1839 about smoke seeping from stoves, considering in particular whether death occurred by asphyxia or because carbonic acid acted as a specific poison. Snow upped the ante. He presented critiques of the scholarly literature, conducted biochemical experiments, some on small animals, many on himself, and prepared tables of his findings. Shortly before Morton announced his discovery of inhalation ether, Snow replicated some of his 1839 experiments and published them after reading of an ill-advised proposal for "absorbing the carbonic acid gas remaining after the explosion of fire-damp in coal mines," which was made, in his view, without due consideration for the diminution of oxygen caused by such explosions.[36] With this background in mind, it seems less surprising that Snow responded to his observations of the inhalation of ether as a chemist, who wondered **(Fig. 51)** whether "by regulating the temperature of the air whilst it is exposed to the ether, we should have the means of ascertaining and adjusting the quantity of vapour that will be contained in it: for the proportion of vapour in any given volume of air saturated with it at any particular temperature, is to the whole volume as the elastic force of the vapour at that temperature is to the atmospheric pressure at the time and place. This is true of all vapours in contact with the liquid which gives them off."[37] As we have seen, he used all of January 1847 to investigate the deductive implications (chemically, technologically, and finally clinically) of this hypothesis. Then, for the next eight weeks, he was an exemplar of John Herschel's dictum **(Fig. 52)**, "that the successful process of scientific enquiry demands continually the alternative use of both the *inductive* and *deductive* method.[38]

* * *

Although the exhibition of his apparatus on the 28th of January was very successful, Snow was troubled. It lacked a mechanism that would permit him to control the amount of vapor the patient inhaled at any particular moment. Removing the mouthpiece from patients if their breathing became labored was awkward, and the sudden inhalation of approximately 50% ether could also be an irritant. So Snow consulted Ferguson, and the two decided that a brass two-way valve with a handle **(Fig. 53)**, inserted into the top of the spiral ether chamber, would allow Snow to ease the patients into full etherization as well as to adjust the strength of the ether/air mixture during the operation itself.[39] Ferguson quickly completed a modified apparatus (the Mark II model, according to Richard Ellis' taxonomy), and Snow used it for three operations at St. George's on the 4th of February. The theater that day was packed with "a numerous assembly of spectators," including a reporter from the Lancet who made note of Snow's revised procedure.[40] With mouthpiece in place, Snow turned the valve on his apparatus so the patient began breathing only atmospheric air. After a short time he gradually turned the valve during successive inspirations, until the patient was inhaling the full strength of ether vapor at the desired temperature. Snow observed the patient's eyes and the character of the respiration for signs of complete insensibility, then nodded to Cæsar Hawkins, who began removing dead bone from the woman's tibia. Snow adjusted the valve several times to keep the patient both unconscious and insensible to pain, using the least amount of ether vapor necessary. Before Cæsar Hawkins finished, Snow turned the valve to admit only air, and the patient awoke during suturing. She had felt no pain. The second operation went almost as well. The patient groaned somewhat at the beginning, but declared afterward that he had felt no pain; the Lancet reporter wondered if the first incision was slightly premature. The third was a complete success, however. Afterward, Snow described his new procedure and credited Ferguson for making it possible. Cæsar Hawkins concluded the morning by expressing thanks, in behalf of his colleagues at the hospital, to Snow for his "superior" apparatus that permitted the administration of controlled amounts of ether vapor.[41] In other words, Snow had become anesthetist at St. George's Hospital – an unpaid position, but one that guaranteed an expansion of his private practice.

Surgical operations at St. George's were performed on Thursday mornings, except for emergencies, so Snow used the intervening week to prepare a paper reviewing his researches and administrations to date. On 11 February, he was in the operating theater at St. George's again. The first operation, a lithotomy on a four year old boy, had the indirect outcome of highlighting the effectiveness of Snow's inhaler and procedure. As Mr. Cutler purposely inserted the sound before etherization had begun, the boy cried lustily; but he stopped crying within seconds of Snow administering ether, and remained insensible while Mr. Cutler searched for the offending stone, found it, and extracted a calculus the size of a pigeon's egg. Snow removed the mouthpiece, and the boy was soon fully awake. During the second operation, a mastectomy, Snow opened the two-way tap on his apparatus fully to atmospheric air, then gradually turned it to increase the amount of ether vapor. After four minutes the woman was till fully sensible, but "rather out of breath."[42] Snow must have been puzzled. This had not happened in the previous seven operations. He checked the apparatus, and observed that the inlet pipe to the ether chamber was capped **(Fig. 54)**. In the words of the Lancet reporter, "she got no ether, and but little air." Snow immediately unscrewed the cap. The sudden inhalation of 50% ether set in motion a train of events that Snow's modified apparatus and procedure were designed to avoid: "Some coughing, and in three or four minutes the face was becoming purple, and the pulse feeble and quick, and the features rather distorted." Snow removed the mouthpiece and stood by as the surgeon, Mr. H. Charles Johnson, amputated the breast without the benefit of controlled etherization. The patient struggled and moaned, but afterwards said she did not remember feeling any pain. Mr. Johnson made no mention of Snow's error, if he even he even recognized it, in his concluding comments. He thought that perhaps the patient's pre-existing bronchitis was the likely reason that the ether "had somewhat disagreed with her."[43]

How could Snow have made such an elementary mistake, given his earlier successes? One possibility is that he had not incorporated into his routine another of Ferguson's modifications to the prototype inhaler – a screw cap on the air intake pipe encircling the outside of the ether chamber **(Fig. 55)**. The intake pipe of the prototype had been uncapped. Ferguson had also added a separate aperture for pouring ether into the chamber, probably so that the two-way tap could be soldered to the lid. Although Snow and the journals only mentioned the latter when describing the new apparatus he had introduced on the 4th of February, it seems likely that Ferguson made all three modifications at the same time.[44]

Two days later, the 13th of February, at the Westminster Medical Society, Snow read a paper **(Fig. 56)** on ether vapor and its use in surgical operations.[45] He began with the pharmacological effects of ether inhalation. His ether uptake table **(Fig. 57)** showed that in any saturated volume of air-ether mixture, the ether vapour displaced a certain quantity of air, the amount depending on the temperature. At 70°F, the temperature he generally preferred for inhalation during surgical operations, the mixture should contain almost 50% ether vapor (he is still unaware that his table is slightly inaccurate for unwashed ether). Since such a concentration would reduce the amount of oxygen in each breath by half, he had been concerned to investigate whether the anesthetic effect was due to asphyxia, which opponents of ether inhalation argued made the procedure a hazardous way to relieve the momentary pains of a surgical operation. So Snow conducted experiments on mice to determine whether ether produced insensibility by excluding oxygen from inspired air. **(Fig. 58)** "Such, however, was not the case, for he found that supplying the displaced oxygen did not counteract the effects of the vapour. Mixed with oxygen gas it affected mice as powerfully as when mixed with the air, as he had found in several experiments. Asphyxia was a very different state from that produced by ether" (383). Asphyxia, while it produced insensibility to pain, was a great danger to life, and ended in death. This was not true of ether, which "allowed the blood to be changed from venous to arterial in the lungs, but probably interfered with the changes which take place in the capillaries of the system. **[Fig. 59]** He had ascertained that a little vapour of ether mixed with air would prevent the oxidation of phosphorus placed in it, and considered that it had a similar effect over the oxygen in the blood, and reduced to a minimum the oxidation of nervous and other tissues" (383). Snow was referring to an observation made by Thomas Graham in 1829, that the presence of certain vapors, including sulphuric ether, would inhibit the slow oxidation of phosphorus in air. That Snow knew of this observation argues a close acquaintance with the literature of experimental chemistry – and buttresses our argument that consilient factors partly explains why Snow was so quick to become an authority on ether inhalation. By using this reaction as an analogy, and transferring the effect from vitro to vivo, Snow implicitly declared himself not a vitalist. In an 1843 article on circulation, he had already situated himself among contemporaries who wondered whether the chemical reactions that maintained body heat, which involved the removal of oxygen from the blood and the production of carbon dioxide, took place in the terminal capillaries, rather than, as was thought by Lavoisier, in the lungs.[46] Snow concluded his paper with some practical observations and advice. Induction of anaesthesia should be as rapid as possible. The depth of anesthesia could be determined by observation of the eye and the nature of the respiration (deep, slow, automatic, but never stertorous). There should be no flinching or groaning when touched by the knife, whether or not the patient remembered any pain. Etherization affected consciousness before sensation. He then described how his modified apparatus permitted him to control the amount of ether inhaled at any time. He recommended that inhalation should always begin with 100% air, then gradually increasing the strength of ether vapor by turning the valve until the patient was inhaling entirely via the apparatus. Thereafter, the two-way tap should be turned as needed to maintain insensibility with the minimum amount of ether vapor.

Snow's paper occupied almost the entire evening of February 13, so discussion was deferred until the following Saturday. For some reason, Snow decided his comments on the possible modus operandi of ether required buttressing. There were no operations at St. George's on the 18th, so he used whatever free time he could squeeze from his general practice for further research. Precisely what he did is unclear, since the minutes for the 20th of February record only that Snow said he "had completed some experiments" since reading his paper the week before.[47] But four years later, he wrote **(Fig. 60)** that "soon after the introduction of the inhalation of ether, I made some observations on the amount of carbonic acid gas exhaled from the lungs under its influence, by passing the expired air through lime water, when I found the quantity to be diminished."[48] It is quite possible that he had repeated the procedures he used in the series of experiments conducted in 1839 on asphyxia and carbon dioxide poisoning. In one set of experiments on white mice and sparrows, "the small quantity of carbonic acid gas given off from the lungs of the animal[s] was absorbed by lime water."[49] In February 1847 he could have used mice or birds, filtered the lime water, washed and dried the deposit, and weighed it, comparing the quantity produced by the same animals during equal durations of time, first conscious, then under the influence of ether.[50] It is also unclear how he determined that "the vapour of ether was given out again from the lungs unchanged," but he may have exhaled ether via a spiral tube into a bottle of sulphuric acid, which was then treated and compared with a similar test on pure ether.[51] Snow was satisfied with whatever experimentation he undertook, for the secretary recorded him as stating that "these circumstances he considered confirmed the explanation of the modus operandi of ether **[(Fig. 61)]** which he had previously given."[52] For Snow, at least, another highlight of the evening must have come when a colleague said "he had seen Dr. Snow's instrument used on many occasions" and then enumerated its advantages "over all others."[53]

Snow, however, was still unsatisfied. In order for his apparatus to work as designed, and to know the precise dosage of ether vapor he was administering, the patient's mouth and nostrils must be completely closed to outside air. The original Tracy mouthpiece **(Fig. 62)** described in mid-January 1847 was similar to others "in ordinary use" – most likely, tube and valves developed by John Read – and, like them, required a separate nose clip, which some patients found disagreeable.[54] Within two weeks, however, Tracy had developed a new mouthpiece that enclosed the nostrils.[55] Some time in February, Snow decided to employ the modified Tracy mouthpiece – **(Fig. 63)** a combination pad of flannel, morocco leather, and rubber. Snow did make a telling modification **(Fig. 64)**, again indicative of the consilient experience he brought to bear on everything relating to ether inhalation: he substituted common for vulcanized rubber, because "the latter frequently, if not always, contains sulphuret of arsenic."[56] He had not forgotten his experiments on arsenic toxicity in cadavers and candles while a medical student at the Hunterian. Since Tracy did not describe his new mouthpiece until after Snow and Ferguson had added the two-way tap to the prototype in late January/early February, there was a period **(Fig. 65)** when the Mark-II inhaler included the original Tracy mouthpiece.

It had been Snow's habit for several years to submit copies of the papers he read rather than rely on journal reporters and the minutes to convey his argument; so, elaborating this procedure, during the second half of February he began preparing a formal article on ether inhalation for his preferred journal, the London Medical Gazette. Meanwhile, on the 25th he again administered ether during three major surgical operations at St. George's Hospital "with the effect of completely removing pain."[57] Two days later, at the Westminster Medical Society, Snow demonstrated the transient effects of ether, when properly administered, on a **(Fig. 66)** Green Linnet – the common name in Yorkshire for the Greenfinch, which were captured, along with (Red) Linnets, by the thousands, then caged and sold on market days throughout England.[58] Snow put a few drops of ether into a glass jar, then inserted a linnet **(Fig. 67)**. It was insensible within a minute. Snow waited another minute until the bird had nearly ceased breathing, quickly withdrew it from the jar, and explained that the gradual recovery of full activity was due to progressive exhalation of ether that had become soluble in the blood – as distinct from asphyxia, where the recovery would have been almost immediate under these conditions.[59] The Society then resumed the adjourned discussion of ether and Snow's paper. One member opined that proper technique always trumped the kind of apparatus used, and rendered the question of temperature irrelevant. "Dr. Snow, in his reply, spoke of the necessity of being able to regulate the proportion of ether vapour and of air," an impossibility if one employed glass instruments with sponges.[60] On the 1st of March, the Pharmaceutical Journal published a very belated description of Snow's first inhaler – the one already superceded by the addition of a two-way tap – and alluded to "a remarkable coincidence" **(Fig. 68)** between Snow's design and an illustration of "Mr. Jeffery's [sic] Apparatus."[61] Snow fired off a blistering letter to the editor: **(Fig. 69)** "it is not a coincidence, but is the result of my previous acquaintance with the former, and approval of it; . . . I have never failed to mention the circumstances when saying or writing anything about the apparatus." For good measure he quoted extracts from the London Medical Gazette and the Lancet.[62] On Thursday, the 4th of March, there were two amputations at St. George's **(Fig. 70)**; "in these . . . the vapour, which was given by Dr. Snow with an equal volume of air until insensibility was induced, was continued in a much more diluted state during the operations, and the patients were also allowed to take two or three inspirations of the external air, now and then, by the nostrils."[63] This should not be necessary if his apparatus was functioning as designed. Snow checked his case notes, believed he had isolated the problem, and submitted his manuscript for publication shortly thereafter.[64]

The London Medical Gazette published "On the Inhalation of the Vapour of Ether," **(Fig. 71)** in two parts, the first on March 19. Like Beethoven in the opening bars of his fifth symphony, he immediately hammered out his principal theme **(Fig. 72)**. "It will be at once admitted that the medical practitioner ought to be acquainted with the strength of the various compounds which he applies as remedial agents, and that he ought, if possible, to be able to regulate their potency. The compound of ether vapour and air is no exception to this rule," although most practitioners seemed to think that all one could do after administering it was to stand by and observe its effects. On the contrary, Snow insisted that its effects varied with the proportion of ether to air, which is within our control. In addition, with a proper apparatus, we can also make certain that patients inhale more ether than they exhale in order to achieve full insensibility (a fundamental premise of what would later be termed pharmacokinetics). In his view, breathing overly diluted ether vapor, not constitutional factors, explained most failures with ether inhalation. Snow concluded the opening paragraph with a reductionistic assertion that justified his biochemical research agenda: "I believe that no sentient being is proof against its influence."[65]

Most of part one consisted of a review of Snow's early reasoning and chemical experimentation. It did contain something new, however – Snow's realization that his ether vapor table was misleading if used to determine how much unwashed ether to administer during operations. The correction was easily made by subtracting four degrees in the temperature column; the percentages and weights were accurate.[66] **(Fig. 73)** But instead of printing a corrected table in the article, Snow had prepared a new table **(Fig. 74)** on a different plan, showing the amount of washed ether vapor that 100 cubic inches would take up at different temperatures, which he believed was more accessible to the average practitioner "unaccustomed for a long period to arithmetical calculations" ("IVE," 499). He explained how the Mark II apparatus **(Fig. 75)** was designed to take advantage of the relationship between the temperature of the air and amount of ether vapor expressed in either table, restated his indebtedness to Jeffreys for the idea of a spiral ether chamber **(Fig. 76)**, complimented Ferguson on his skillful contrivances, and mentioned his preference for the latest Tracy mouthpiece.

Part two, in the following number, featured Snow's description of the procedure for ether inhalation he employed and his clinical observations of patients undergoing surgical operations. One thing was paramount – "the shorter the process the better" (502). Constricted pupils, with the eyes turned up, and respiration that was deep, slow, and regular, indicated that the stage of insensitivity to pain had been reached; the operation should not begin before this stage. He had often observed that the pulse, which was generally more rapid and feeble than normal, regained its previous strength when the inhalation was discontinued. He believed, based on clinical epidemiological observations, that the cause was due to a fault in his apparatus. Among his patients to date, children "inhaled more easily than the adults generally did . . . [and] were more quickly affected, generally becoming insensible in less than two minutes, and always without any of the struggling which sometimes occurred in adults" (540). Since used the same inhaler, the only difference was that "the tubes were wider in proportion for children than adults" (540). Shortly before submitting the manuscript, he had disassembled one of his apparatus and found that the internal width of the tube, supposed to be five-eights of an inch throughout, was sometimes reduced to half an inch. He noted that "I am now getting elastic tubes, valves and mouth-tubes, made purposely for the apparatus three quarters of an inch in diameter . . ." (541).[67] **(Fig. 77)** The editors permitted him to add a footnote to the effect that the wider tubes worked as expected. He concluded the article with the observation **(Fig. 78)** "that I am inclined to look upon the new application of ether as the most valuable discovery in medical science since that of vaccination" (541).

* * *

If so, Snow had done more than anyone else to make it happen. In the first month of 1847, he had established a fundamental anesthetic principle – that the amount of ether vapor in air increases with the temperature of the ether – and put it in practice by formulating an SVP table and designing an apparatus, by virtue of which he could select and control the amount of ether inhaled by patients in surgical settings. In subsequent weeks, Snow continued this three-stage feedback loop – responding to clinical problems by making a series of empirical adjustments in his apparatus, engaging in additional experimentation, presenting his findings at the Westminster Medical Society, and finally preparing an article for the London Medical Gazette that made public everything he had done. By comparison, James Robinson's Treatise on ether, which had appeared in late February, was anecdotal and self-congratulatory. By the end of March, John Snow was the acknowledged medical authority on the inhalation of ether, and Robinson's meteoric fame was eclipsed. Snow did not rest on these laurels, although during the remainder of 1847 he markedly reduced the pace of research while serving as the unofficial spokesman for the notion that anesthesia should be a branch of scientific medicine.

David Zuck would sum up as follows: In this *annus mirabilis* of 1847, Snow established the practice of general anesthesia by inhalation on a sound scientific footing, whereas many of his contemporaries, including Robinson, approached it solely as an empirical art.[68] In addition, Snow set an agenda for research into the pharmacology of anaesthetic agents that was so far in advance of his times, that after his death in 1858 it was not resumed until the middle of the next century. I agree.

But if the two faces of the Roman god, Janus, is a metaphor for history, I myself would stress the face that looks backward: In my view, it was Snow's good fortune that ether inhalation jelled with his prior scientific interests and medical expertise in respiratory physiology and diseases, narcotics, and poisons. His rapid and successful investigation of the scientific properties and clinical applications of the vapor of ether in 1847 was made possible, in large part, because of luck and consilience.

Notes

1. The three friends were "Mr. Stocks, Mr. Snow, and Mr. Fenney"; "Letter from Mr. J. Robinson, Surgeon-Dentist to the Metropolitan Hospital," MT 15 (2 January 1847): 274. For particulars on Robinson's life and training, see Richard H. Ellis, "James Robinson, England's True Pioneer of Anaesthesia," in The History of Anesthesia, Third International Symposium, Proceedings (Park Ridge, IL: Wood Library-Museum, 1992), 153-64.

2. The new apparatus was constructed by "Mr. Elphick, of Castle-street, Oxford-street."; "Letter from Mr. J. Robinson," MT 15 (1846): 274. An engraving and description appears in Treatise, 17-18. M. Elphick was primarily a painter and glazier, with premises at 28 Castle Street, Oxford Circus; Pigot, Directory of London (London: Pigot & Co., 1839), 141. Receiving it on Saturday, 26 December, Robinson tested it on his servant before using it successfully on two patients. He was equally satisfied with the apparatus in three more extractions, before demonstrating it to Snow on the 28th.

3. We have constructed a scenario based on James Robinson, Treatise, 8-9, 13-14, 16-19.

4. Robinson, Treatise, 8.

5. Robinson, Treatise, 8.

6. Robinson, Treatise, 8.

7. Robinson, Treatise, 8; "Letter from Mr. J. Robinson," MT 15 (2 January 1847): 274; Treatise, 8.

8. "Medical Intelligence: Animal magnetism superseded —discovery of a new hynopoietic," LMG 38 (18 December 1846): 1085-86.

9. J. Chitty Clendon, Letter to the Editor, Lancet 1 (1847): 50; "Apparatus for inhaling ether," PharJ 6 (1846-47): 338. The editors of PharJ also stated that "we are informed that Dr. A. T. Thomson has been in the habit of exhibiting to his class the effects of ether when inhaled, in order to demonstrate the analogy in its effects with that of the nitrous oxide gas. The practice has recently been discontinued, as it was found to irritate the lungs of some persons, and in one case produced inflammation. Mr. Squire [the chemist] considers that this arose from the ether not having been previously washed with water"; Ibid. Anthony Thomson was Professor of Materia Medica and Therapeutics, as well as Forensic Science, at University College and Physician to University College Hospital; Medical Directory (1846). He was also a colleague of Snow's at the Westminster Medical Society.

10. John Snow, "Circulation of capillary blood-vessels" (1843), 813.

11. Merrington stated that "an assistant of [William] Morton came over to this country and on the 11th November [1846] demonstrated the anaesthetic properties of ether at a meeting of the Medico-Chirurgical Society in London"; William R. Merrington, University College

Hospital and its Medical School: A History (London: Heinemann, 1976), 31. If correct, then it is possible that Snow, a Fellow since 1843, was in attendance. However, published minutes from that meeting make no mention of such a demonstration; MT 15 (1846-47): 184-85. Medico-Chirurgical Transactions 29 (1846) contain no record of such an event, either.

12. "Medical Intelligence. Performance of surgical operations during the state of narcotism from ether," LMG 39 (1847): 38-39; Mr. Squire's inhaler "consisted of the bottom part of a Nooth's Apparatus . . . and one of Read's flexible inhaling tubes" (39). "The sedative effect of ether tested in the operating theatre of the North London Hospital," [previous name for University College Hospital] PharJ 6 (1846-47): 337-38; the editor noted that "we have been informed that some experiments have been made at other hospitals, but hitherto with less marked success . . ." (338). An engraving of Squire's apparatus appeared on the same page.

13. Lancet 1 (1847): 7; the first Lancet issue of 1847 devoted almost three pages to material submitted by Dr. Francis Boott, including a copy of a paper that Henry J. Bigelow, M.D., read at the Boston Society of Medical Improvement on 9 November 1846 describing mixed outcomes observed in Dr. Morton's dental office and at the Massachusetts General Hospital. Boott also submitted a brief account of Robinson's first dental operation in London on 19 December and a note he had received from Robert Liston that Mr. Squire's ether inhaler had worked well in two surgical operations.

14. "Painless surgical operations," MT 15 (2 January 1847): 271. Robinson had a different opinion of his first inhaler, used initially on 19 December. He referred later to it as "a very imperfect apparatus, hastily got up." Although it worked adequately on Miss Lonsdale, he was unable to produce complete insensibility in several patients the following day; Robinson, Treatise, 5. See also David Zuck, "William Hooper (1818-1878) and the Early Weeks of Anaesthesia in England," in History of Anaesthesia Society, Proceedings 34 (2004): 48-60.

15. "Painless operations," MT 15 (9 January 1847): 290.

16. Ibid.

17. John Snow, "On the inhalation of the vapour of ether," LMG 39 (1847): 500, 499; hereafter cited parenthetically as "IVE."

18. John Dalton, A New System of Chemical Philosophy vol. 1, pt. 1 (1808; reprint, with an introduction by Alexander Joseph, London: Peter Owen, 1965). There was nothing prescient about Dalton's choice of ether; it was simply a suitable volatile liquid for his purposes.

19. Andrew Ure, "New experimental researches on some of the leading doctrines of caloric; particularly on the relation between the elasticity, temperature, and latent heat of different vapours; and on thermometric admeasurement and capacity," Philosophical Transactions of the Royal Society of London 108 (1818): 338-94.

20. The formula was as follows: since the elastic force of ether is 30 inches of mercury at its boiling point of 104° Fahrenheit, to find the elastic force at 10° below the boiling point, divide 30 by 1.22; at 20°F below the boiling point, divide that quotient by 1.23; etc., increasing

the divisor by 0.01 for each interval of 10°F below the boiling point; Ure, 350.

21. “Westminster Medical Society,” Lancet 1 (1847): 99.

22. David Zuck, “Julius Jeffreys – Pioneer of Humidification,” in History of Anaesthesia Society, Proceedings 8b (1990): 70-80.

23. “Surgical Operations with the Vapour of Ether at St. George’s Hospital,” LMG 39 (22 January 1847): 168.

24. “Westminster Medical Society,” LMG 39 (22 January 1847): 156; Lancet 1 (23 January 1847): 99.

25. “Table,” MT 15 (1846-47; 23 January 1847): 325.

26. “Westminster Medical Society,” Lancet 1 (30 January 1847): 120-21. Tracy was an unqualified Surgeon-Dentist to St. Bartholomew's Hospital at the time who quickly began to specialize in anaesthesia; he administered ether for the first Caesarian section described as being performed under ether anaesthesia, in January 1847; S. J. Tracy, “The use of ether vapour in surgical operations,” LMG 39 (5 February 1847): 258. In 1849 he qualified as a Member, Royal College of Surgeons; Medical Directory (1853).

27. H. Charles Johnson, assistant surgeon at St. George’s Hospital, was a Fellow of the Westminster Medical Society and could have seen Snow demonstrate his apparatus on the 16th and recommended him to the hospital governors.

28. “Operations without Pain. St. George’s Hospital,” Lancet 1 (6 February 1847): 158.

29. “Westminster Medical Society,” Lancet 1 (30 January 1847): 121.

30. “Operations without Pain. St. George’s Hospital,” Lancet 1 (6 February 1847): 158.

31. Ibid.

32. Ibid.

33. “Order of attendance on lectures . . . to pass both the Hall and the College,” Lancet 1 (1837-38): 6; Vinten-Johansen, et al., Cholera, Chloroform, and the Science of Medicine: A Life of John Snow (New York: Oxford University Press, 2003), 30.

34. Snow, “Arsenic as a preservative of dead bodies,” Lancet 1 (1838-39): 264.

35. At the 16 December 1837 meeting, “Mr. Josh. Toynbee, and Mr. Snow, had conducted a series of experiments on these candles, to ascertain the effects of their combustion on animal life. They found that guinea-pigs, exposed to a constant stream of vapour, from six of these candles [stearin], for two separate periods of eight hours each, were not at all affected, even though the temperature of the box, through which the vapour passed, was occasionally as high as 110°. The animals ate their food, which was constantly exposed to the gas. The experiments were subsequently repeated, and carried on for a period of six days, in a temperature never

exceeding 80°, with the same results. Two candles were then made, each contained a drachm of arsenious acid; the vapour from these did not affect the guinea pigs. Subsequent experiments with some birds had been instituted, but owing to the apparatus having ignited, no satisfactory conclusion could be drawn from them; for, though one of the birds perished in the smoke caused by the fire, the other lived for four hours, after drinking with great avidity during that time. The stomach, and commencement of the intestinal tube in each of these birds, were found of a bright red colour"; "Westminster Medical Society," Lancet 1 (1837-38): 463.

36. Snow, "On the pathological effects of atmospheres vitiated by carbonic acid gas, and by a diminution of the due proportion of oxygen, Edinburgh Medical and Surgical Journal 65 (1846): 56. An example of Snow's modus operandi: "*First Experiment.*-- Into a large glass vessel, containing 2000 cubic inches of atmospheric air, inverted over water, 70 cubic inches of nitric oxide gas were passed, which, combining with part of the oxygen of the air, formed nitrous and nitric acid, which were absorbed by the water. After the entire absorption of these acids, and the volume of the air had been restored to 2000 cubic inches, the composition of this factitious atmosphere was found to be 18 ½ oxygen, 81 ½ nitrogen in every 100 parts, the oxygen being reduced 2 ½ per cent. Into this a white mouse was introduced, and the small quantity of carbonic acid given off from its lungs was absorbed by lime water. It seemed unaffected, and was taken out at the end of five hours"; Ibid., 50-51.

37. Snow, "On the inhalation of the vapour of ether," LMG 39 (1847): 498.

38. John F. W. Herschel, A Preliminary Discourse on the Study of Natural Philosophy (1830; Chicago: University of Chicago Press, 1987), 175; italics retained. Others have pointed to Snow's early scientific training and research as reasons why he was out of the blocks so quickly in developing an efficient ether inhaler. For example, see David A. E. Shephard, "John Snow and research," Canadian Journal of Anaesthesia 36 (1989): 224-41; Richard H. Ellis, "The inhalers of Dr. John Snow: his marks and his score," in History of Anesthesia Society, Proceedings 8b (1990): 81; Rod K. Calverley, "An early ether vaporizer designed by John Snow," in The History of Anesthesia, Third International Symposium, Proceedings (Park Ridge, IL: Wood Library-Museum, 1992); Shephard, John Snow, Anaesthetist to a Queen and Epidemiologist to a Nation: A Biography (Cornwall, P. E. I., Can.: York Point, 1995). It is also a theme in Vinten-Johansen, et al., Cholera, Chloroform, and the Science of Medicine: A Life of John Snow (New York: Oxford University Press, 2003).

39. "Etherized air from the apparatus was gradually let on, by means of a tap, opening two ways, which had been added since the previous week, and which Dr. Snow said Mr. Ferguson, the instrument maker, had contrived"; "Operations without Pain. St. George's Hospital," Lancet 1 (13 February 1847): 184. Rod K. Calverley's description of the Wood Library-Museum's Mark II apparatus indicates that the "tap" was made of brass: "a brass quadrant valve which could be turned to allow the inspired vapor to be diluted with room air"; "An early ether vaporizer designed by John Snow," in The History of Anesthesia, Third International Symposium, Proceedings (Park Ridge, IL: Wood Library-Museum, 1992), 92.

40. "Operations without Pain. St. George's Hospital," Lancet 1 (13 February 1847): 184.

41. Ibid. Implied in Hawkins' remarks was recognition of Snow's intuition and research in developing the ether table, which was essential for anyone who sought to regulate the proportion of ether and atmospheric air administered to the patient. Two more medical journals published this table in the week after Snow's first operations at St. George's: "Table for calculating the strength of ether vapour," LMG 39 (29 January 1847): 219-220; "Table of the Quantity of the Vapour of Ether in One Hundred Cubic Inches of Air," PharJ 6 (1846-47; 1 February 1847): 361.

42. "Operations without Pain. St. George's Hospital," Lancet 1 (20 February 1847): 210.

43. In his case note on this operation, Snow does not admit to making an error. Instead, he wrote that the patient's bronchitis made her sensitive to the ether, resulting in coughing and a decision to leave off the ether for the duration of the operation; Snow, On the Inhalation of the Vapour of Ether in Surgical Operations (London: Churchill, 1847), 58. It is possible, of course, that the Lancet reporter's observation was incorrect. The reporter for LMG accepted Johnson's explanation that the ether was discontinued because of the bronchitis; "Westminster Medical Society," LMG 39 (1847): 384 ftn.

44. If one exempts variations in the mouthpiece, Richard H. Ellis' taxonomy remains accurate for the Mark I prototype (23 January 1847) and the Mark II version, although the date of the latter should be 4 February 1847 (first public demonstration) rather than 19 March (when an illustration first appeared). See Ellis, "The inhalers of Dr. John Snow: his marks and his score," in History of Anesthesia Society, Proceedings 8b (1990): 81, although this is only an abstract of Ellis's presentation. For the dates of Snow's four ether inhalers, see Rod K. Calverley "An early ether vaporizer designed by John Snow," in The History of Anesthesia, Third International Symposium, Proceedings (Park Ridge, IL: Wood Library-Museum, 1992), 94.

45. "Westminster Medical Society. Observations on the vapour of ether, and its application to prevent pain in surgical operations," LMG 39 (1847): 383-84.

46. David Zuck, "Thomas Graham," in History of Anaesthesia Society, Proceedings 17 (1995): 36-42. On contemporary belief in the capillaries as the seat of this metabolic process, see John Elliotson: "As it is now generally believed that the oxygen which enters into the blood combines with the carbon, not in the lungs, but in all the extreme vessels, and in them forms carbonic acid, the evolution of heat throughout the body is thus at once explained – it is a mere instance of combustion in the extreme vessels, the union of carbon and oxygen being always attended by an increase in temperature"; Human Physiology, 5th ed. (London: Longman, 1840), 238. Approximately three decades later, it was demonstrated that the process took place in the cells.

47. "Westminster Medical Society," LMG 39 (1847): 384.

48. Snow, "On narcotism by the inhalation of vapours," part 16, LMG 47 (11 April 1851): 625; he cited the minutes of the 20 February 1847 meeting of the Westminster Medical Society.

49. Snow, "On the Pathological Effects of Atmospheres vitiated by Carbonic Acid Gas, and by a diminution of the due proportion of Oxygen," Edinburgh Medical and Surgical Journal 65 (1846): 51; the quote is from the fifth experiment.

50. Another method would have been to use a manometer to measure the volume change in a closed container while absorbing the CO2 in lime water. Under etherization, less oxygen would be used, and less CO2 put out, if the metabolism was depressed – hence an additive effect on the readings, increasing the sensitivity.

51. Ibid., part 15, LMG 46 (1 November 1850): 749-50.

52. "Westminster Medical Society," LMG 39 (1847): 385. Snow's subsequent researches, as detailed in "On Narcotism," only solidified his attachment to this analogical hypothesis: "The diminution of the amount of carbonic acid formed in the system under the influence of chloroform, ether, and alcohol, taken in conjunction with a circumstance shown in a former paper, that the chloroform and ether are exhaled unchanged from the blood, assist to prove a view of their modus operandi which I suggested with respect to ether, early in 1847 [note citing LMG 39 (1847): 383]. That view may be stated as follows.

Chloroform, ether, and similar substances, when present in the blood in certain quantities, have the effect of limiting those combinations between the oxygen of the arterial blood and the tissues of the body which are essential to sensation, volition, and, in short, all the animal functions. The substances modify, and in larger quantities arrest, the animal functions, in the same way, and by the same power, that they modify and arrest combustion, the slow oxidation of phosphorus, and other kinds of oxidation unconnected with the living body, when they are mixed in certain quantities with the atmospheric air"; LMG 47 (11 April 1851): 626.

53. "Westminster Medical Society," LMG 39 (1847): 384. The discussion on the 20th included the earliest mention we have found of what later was termed the a la reine method: "Mr. Norman had seen the ether exhibited to an infant eight months old . . . . It was administered by sprinkling a little ether on a handkerchief, and holding it before the mouth and nose of the little patient."

54. See Calverley, "An early ether vaporizer," 97. Tracy's apparatus included "an elastic tube . . . of 16 inches in length, which is surmounted by a double-valved mouthpiece of the description in ordinary use, a steel compress, padded, being used for securing the nostrils. It has been hinted to me that a valve made of some fine tissue, and secured to the top of the mouth-cap, would be an improvement on the compress in general use, as many patients dislike their noses being secured by such an instrument"; S. J. Tracy, "Apparatus for the Respiration of Ether Vapour," LMG 39 (22 January 1847): 167.

55. "In administering the vapour of ether to a patient in the recumbent position, it was found the valves would not act until the patient's head was raised and the valve-piece became perpendicular. To remedy this, I have secured the end of an elastic tube 2 inches in length into the valve-piece, which terminates in a mount, on which is placed a pad with a hole in the centre formed of 10 or 12 thicknesses of flannel and covered with morocco, somewhat of an oval shape, being 5½ inches in its long and 4 inches in its short diameter. A mouth-piece of ivory or silver, an inch in length from the worm, with a good-sized bore and pierced by several transverse holes,

is screwed into the mount, over which a piece of vulcanized rubber larger than the pad with a hole in its centre is placed. The person who administers the vapour can easily press this on the patient's mouth, and compress the nose with the same"; S. J. Tracy, "The use of ether vapour in surgical operations," LMG 39 (5 February 1847): 258.

56. Snow, "IVE," LMG 39 (19 March 1847): 500.

57. "St. George's Hospital," LMG 39 (12 March 1847): 482.

58. Standard field guides, such as Lars Jonsson's Birds of Europe (Princeton, NJ: Princeton University Press, 1993), do not list a green linnet. Neither does John Gould, The Birds of Great Britain (1873). We thank Betty Vinten-Johansen for resolving this little mystery by consulting T. H. Nelson, The Birds of Yorkshire, vol. 1 (London: A. Brown & Sons, 1907). For the Greenfinch (formerly *Ligurinus chloris*, currently *Carduelis chloris*): "Of local names, Green Linnet and Green Lenny are general" (165). With respect to the Linnet (*Linota cannabina*, currently *Carduelis cannabina*): In the autumn, "they often remain for some time on the sand-dunes and waste lands near the coast, afterwards resorting to the stubbles where they feed in company with Greenfinches and other small birds, and it is at these times that large numbers fall victims to the snares of the bird-catchers" (186). Among local names for Linnet was Red Linnet.

59. "Westminster Medical Society," Lancet 1 (6 March 1847): 259.

60. Ibid.

61. "Apparatus for inhaling ether," PharJ 6 (1846-47; 1 March 1847): 423-24.

62. "To the editor of the Pharmaceutical Journal," PharJ 6 (1846-47; 1 April 1847): 474-75.

63. "Operations without pain. St. George's Hospital," Lancet 1 (3 April 1847): 368.

64. Internal evidence makes it possible to establish that Snow probably submitted his manuscript sometime in the period 4-10 March. He wrote ("IVE," 540) that he had administered ether in thirteen surgical operations at St. George's Hospital; the thirteenth occurred on 4 March. His fourteenth and fifteenth were on 11 March; Snow, On the Inhalation of the Vapour of Ether in Surgical Operations, 60.

65. Snow, "IVE," LMG 39 (19 March 1847): 498.

66. "The table you honoured me by publishing in the February number, is correct for ether, which is not free from alcohol, and boils at 104°. To make it correct for washed ether, which boils at 100° four degrees must be deducted; for instance, for 40° read 36°, and so on [for example, the 53.6% ether vapor listed for 74°F is correct for 70°F], and for washed ether deprived of its water by potash, and boiling at 98°, six degrees must be deducted"; "To the editor of the Pharmaceutical Journal," PharJ 6 (1 April 1847): 474-75.

67. In a footnote, Snow wrote "Since the above was written, I have used these large tubes, and found them to answer my expectations"; "IVE," 541. He first used the modified apparatus in

operations at St. George's on 18 March; "Operations without pain. St. George's Hospital," Lancet 1 (3 April 1847): 368.

68. David Zuck, "Physics of heat and vaporization: Its history and application to the design of anaesthetic vaporizers," CPD [Continuous Professional Development] Anaesthesia 1 (1999): 88-93.