On Monday morning, 28 December 1846, John Snow, M.D., was among three medical friends whom dentist James Robinson had invited to his home surgery in Gower Street, several blocks south of University College Hospital, central London. The intention was to demonstrate the effectiveness of a new ether inhaler, constructed according to his specifications by a local medical-instrument technician. Robinson prepared it

Abbreviations Used in the Notes

“IVE” “On the inhalation of the vapour of ether”
LMG London Medical Gazette
MT Medical Times (London)
PharmJ Pharmaceutical Journal (London)

1. The three friends were “Mr. Stocks, Mr. [sic; Dr.] Snow, and Mr. Fenney”; “Letter from Mr. J. Robinson, Surgeon-Dentist to the Metropolitan Hospital,” Medical Times (hereafter MT) 15 (2 January 1847): 274; the letter is dated “Dec. 28” [1846]. 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 (2 January 1847): 274. An engraving and description appear in James Robinson, A Treatise on the Inhalation of the Vapour of Ether (London: Webster, February 1847), 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
carefully, using washed ether. Both Robinson inhalers were modifications of Nooth’s glass apparatus, which had been invented in 1776 to make soda water in the home.\(^3\)

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 instructed him how to inhale from the mouthpiece, and applied a clip to his nostrils. According to his 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 ether in Dr. Francis Boott’s home (when he had rendered Miss Lonsdale insensible before extracting a molar), 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 removed the rotten tooth the old-fashioned way.\(^5\)

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.” Al-

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though Robinson was able to remove a diseased molar in seconds, it took the girl four minutes to "recover her faculties"; she immediately "complained of headache and oppression." She felt better after drinking a glass of water, to which a drop of ammonia had been added. Since "she could give no account of her state, and was unaware [of] 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."

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 a vaporizer that he believed was vastly superior to those currently in use, including Robinson’s inhaler. 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 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,” “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.”

There is no evidence that Snow ever used ether

6. Ibid.
"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."\textsuperscript{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 had recommended their therapeutic value for the relief of respiratory congestion. He also knew that ether did not act like a typical poison since he had determined that it was a gas which, like carbon dioxide, "escape[d] with the breath."\textsuperscript{10} So his mind was hardly a blank slate when he observed Robinson administer ether at the end of December 1846.\textsuperscript{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

\textsuperscript{9} J. Chitty Clendon, Letter to the Editor, \textit{Lancet} 1 (9 January 1847): 50; "Apparatus for inhaling ether," \textit{PharmJ} 6 (1 January 1847): 338. The editors of \textit{PharmJ} 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; \textit{Medical Directory} (1846). Like Snow, he was a member of the Westminster Medical Society.

\textsuperscript{10} John Snow, "Circulation of capillary blood-vessels" \textit{LMG} 31 (3 March 1843), 813.

\textsuperscript{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, \textit{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; \textit{MT} 15 (5 December 1846): 184-85. \textit{Medico-Chirurgical Transactions} 29 (1846) contain no record of such an event, either.
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.”¹² On 2 January, however, 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 In the January 2 issue of *Medical Times*, the editors excitedly mentioned the arrival of news from America of this new discovery and the initial trials of it in London, noting that “the great obstruction to its general adoption in the metropolis, in all severe [major] operations, has been the difficulty of securing

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¹². “Medical Intelligence. Performance of surgical operations during the state of narcotism from ether,” *LMG* 39 (1 January 1847): 38-39; Peter Squire’s vaporizer “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,” *PharmJ* 6 (1 January 1847): 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. It is unclear why PharmJ preferred North London to University College Hospital. The name was changed in 1837; Merrington, *University College Hospital and its Medical School*, xv.

¹³. *Lancet* 1 (2 January 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 vaporizer had worked well in two surgical operations.
an apparatus which, while admitting a free respiration, allows an uninterrupted inhalation of the vapour of ether. An elegant apparatus, which obviates all these difficulties, has been constructed by Mr. Robinson, of which we give an engraving in the present number.”

But the engraving was not available when the issue went to press, so it appeared the following week. By then it was already outdated by the new inhaler Robinson had used in Snow’s presence and which the Medical Times editors had observed Robinson employ in demonstrations at the hospitals of King’s College and University College. The editors tried to salvage this embarrassment with an assertion that the new vaporizer was, with a minor exception, “similar in every respect to the above [woodcut].” It was, like the original, “a most perfect apparatus.” The editors also endorsed Robinson’s modified inhaler via counter-examples at Peter Squire’s expense: At University College Hospital eight days earlier, Squire’s apparatus 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.” This 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; the patient became perfectly insensible in two minutes, and the operation was completed before the patient was aware that it had commenced.”

14. “Painless surgical operations,” MT 15 (2 January 1847): 271. Robinson, however, was very dissatisfied with the vaporizer he first employed on 19 December and which MT planned to illustrate. 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.


16. Ibid.
During the fortnight after observing Robinson employ a modified Nooth’s-apparatus inhaler, Snow had confirmed a suspicion— that the inconsistent results he observed at the dentist’s surgery and read about in the medical journals were caused by variations in the temperature of the air after passing over liquid ether contained in apparatus constructed of glass. He had secured a glass vessel, inserted sponges soaked with ether, and using “a delicate thermometer,” had 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 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 only by empirical tinkering with their apparatuses, Snow’s initial approach was totally different. He looked to chemistry and physics.

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 *New System of Chemical Philosophy* that he published three years later contained SVP tables over a range of temperatures for various volatile liquids, including ether.18


Andrew Ure, "Doctrines of caloric,” 363 (table 4).

**Manometer**

Andrew Ure, "Doctrines of caloric,” 394 (Fig. 1, plate 20).
physician and pioneer of industrial chemistry, Andrew Ure, recalculated Dalton’s tables in a search for greater accuracy, and published his results in an 1818 essay on "Leading doctrines of caloric." With respect to ether, Ure proposed a set of ratios for the elastic force that accorded closely with actual measurements he conducted over mercury, using a manometer of his own devising.

If Ure’s table was accurate, Snow could save himself a lot of work. Replicating Ure’s apparatus as closely as he could, he repeated Ure’s experiments (“IVE,” 498-99). His first result coincided with Ure’s figure for 44°F, so he repeated the process in 10° increments between 44° and 84°. When these results also agreed with Ure’s table, he had confirmed the first part of his hypothesis: the amount of ether vapor in air increased with temperature — doubled, in fact, between 44°F and 74°F. Hence, 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 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 accepted formulas 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

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°F, 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, "Doctrines of caloric," 350.

medical journals for publication; multiple publication was the norm in those days.

Next he began to design a vaporizer that would permit him to control the temperature of the ether over which the air would pass. Metal was a good conductor of heat, and water a good reservoir. His idea was to construct an apparatus using both, the warm water to provide the heat safely, while pegging the concentration of ether according to its temperature, and the metal to conduct it. It occurred to Snow that a vaporizer constructed partially on the principle of the Jeffreys humidifier (which he had used in his practice since 1842) might meet his expectations (“IVE,” 500). He took his design to Daniel Ferguson at 21 Giltspur Street, Smithfield, surgeon’s instrument-maker to St. Bartholomew’s Hospital, who agreed to have it ready in several days. The vaporizing chamber was a round tin box; to the underside of the lid a volute similar to Jeffreys’ was soldered, which Snow anticipated would increase ether uptake by lengthening the surface over which the air had to travel. A flexible tube led to the mouthpiece and the entire vaporizer was immersed in a basin of water at the required temperature.

Meanwhile, the second and third weeks of January were eventful elsewhere in London also. Surgeons at most of the major hospitals had tried the new process for painless surgery, attested by the considerable number of different inhalers already in use. Twelve were presented and discussed on the 13th at the Pharmaceutical Society, including a modified version constructed by Squire and three that Ferguson had contrived for different surgeons. The weekly issue of

22a. “On the inhalation of the vapour of ether, and the apparatus used for the purpose,” PharmJ 6 (1
the Lancet on Saturday, the 16th of January, featured Hooper’s latest apparatus, based on designs provided by Boott and Robinson.22b This diversity of apparatus reflected inconsistent results in the administration of ether vapor. While some surgeons and dentists raved about their inhalers, the medical journals reported some failures, the most abject occurring with the model used 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, since 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

On the evening of the 16th, “Inhalation of ether” was the main event at the weekly meeting of the Westminster Medical Society, held at Exeter Hall, Strand, near the Waterloo Bridge. 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 and said 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.

He concluded with a brief overview of the apparatus “which Mr. Ferguson, of Smithfield, was making for him,” based “on the plan of the humidifier designed by 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, a good conductor of caloric, would be cheap and portable.”

The following week, Daniel Ferguson delivered the vaporizer to Snow’s surgery. 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 society’s minutes from the previous week, but Snow’s elaborate table of ether vapor at different temperatures had been reduced to five entries. Fortunately, he had submitted the full table to the *Medical Times*, where it appeared the following day. At 8:00 o’clock that evening, Saturday the 23rd, only a few dozen members of the Westminster Medical Society were in attendance for Snow’s demonstration. The vaporizer 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 that it was

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necessary to warm the air before it entered the ether chamber. Inside the box, 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. The operator, after adding ether, would attach a flexible tube, with an inner diameter of five-eights of an inch, to the central pipe, 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, Snow modified a design by Samuel J. Tracy of Bart’s, perhaps on Ferguson’s recommendation since he had constructed it as well. 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, 28 January, at St. George’s Hospital, Hyde Park Corner, just west of Green Park and Piccadilly. It is unclear whether Snow had proposed this trial, or whether the hospital governors figured they had little reputation left to lose by asking a local physician with an untested apparatus to administer ether for their skeptical surgeons. The trial was public, with spectators and reporters filling the benches of the

Snow’s first mouthpiece

Tracy’s original mouthpiece


D St. George’s Hospital.


27. H. Charles Johnson, assistant surgeon at St. George’s Hospital, was a Fellow of the Westminster
amphitheater, and for Snow, the circumstances were less than ideal. He would be administering ether for three different surgeons, performing three very different operations, on three patients of different ages and physical conditions. Moreover, Snow’s only baseline for deciding how much vapor to administer was one test, in which his apparatus heated to 70°F produced a powerful effect in thirty seconds — but he had no idea, as yet, how long it would take to produce insensibility at that temperature.

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°F, which, according to his table, should deliver about 44% ether vapor (green shaded rectangle). But the ether supplied by most hospitals was washed, which boiled at 100°F, whereas the unwashed ether he had used when confirming Ure’s figures boiled at 104°F. 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.” 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.” Hawkins was impressed.

Snow’s first trial of ether table and prototype apparatus in a surgical setting
(Operation on William Daphne)

Unwashed liquid ether at 65°F
Washed liquid ether at 104°F


Medical Society and could have seen Snow demonstrate his apparatus on the 16th and then recommend him to the hospital governors.

31. Ibid.
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, so he increased the water temperature to 70°F. Mr. Cutler commenced the operation after two minutes of inhalation. Snow employed the same intermittent technique, but with greater effectiveness. Cowen awoke without stirring or having experienced any pain. Cutler, also, was impressed, and said so to the assembled spectators. Snow’s success continued with the third patient, Francis Lewis, a man of forty-two 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°; 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

* * *

How did it come about that Snow focused on temperature as the ideal mechanism for controlling the amount of ether administered to patients?

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. That is, virtually all his experimental work was fundamentally physico-chemical, as opposed to the pharmacological approach of such researchers as François Magendie, Marie-Jean-Pierre Flourens, Claude Bernard, and Nikolay Ivanovich Pirogov.33

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33. For example, the Russian surgeon N. I.
In all likelihood, this orientation began during his apprenticeship in Newcastle-upon-Tyne. 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. While working as Joseph Warburton’s assistant at Pateley Bridge, North Yorkshire, he began to distill his drinking water, and devised a test of its purity. At the Hunterian School of Medicine in London, he took two chemistry courses from John Hunter Lane, an Edinburgh trained surgeon and physician, although the regulations required only one.\textsuperscript{33a}

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 cadaveric vessels with arsenic to clear them of dried blood before adding ink. He repeated the procedure the following summer. 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

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Pirogov, applied liquid ether to the peripheral nerves, the spinal cord, and the surface of the brain, as well as injecting it into arteries and veins; \textit{Researches Practical and Physiological on Etherization}, trans. B. R. Fink (St. Petersburg, 1847; Park Ridge, IL: Wood-Library Museum, 1994). Snow’s researches, on the other hand, were concerned with estimating the concentration of ether in the inhaled air and the circulating blood, and relating the levels with the depth of anaesthesia. They were chemical and quantitative investigations with a practical purpose, which were not taken up again until nearly a century after his death; David Zuck, “John Snow – Reductionist?” in P. M. E. Drury, ed., \textit{The History of Anaesthesia, Sixth International Symposium} (2006), Proceedings (Reading, UK: History of Anaesthesia Society, 2007): 221-32.

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 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.34

After qualifying as a surgeon-apothecary in October 1838, Snow exchanged cramped lodgings in Bateman’s Buildings, Soho Square, for a rented flat in nearby Frith Street which had sufficient room to set up a surgery and home laboratory. One of the first research projects he conducted in his new premises was a bio-chemical experiment to replicate the decomposition process in the cadavers he had worked with at the Hunterian School. He isolated metallic arsenic from the emitted gases and published his findings in a letter to the Editor of the Lancet, his first publication in a

34. 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°[F]. 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 (23 December 1837): 463.
medical journal.\textsuperscript{35} Thereafter, Snow continued to demonstrate a lively interest in possible chemical explanations for the medical and public health problems of his time. For example, in 1839 the Westminster Society became quite exercised about smoke seeping from stoves, considering in particular whether death occurred by asphyxia or because carbonic acid acted as a specific poison. Snow went further, presenting critiques of the scholarly literature, conducting biochemical experiments, some on small animals, many on himself, and preparing tables of his findings.\textsuperscript{35a} In 1846, Snow replicated some of these 1839 experiments and published them, after reading about 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.\textsuperscript{36}

With this background in mind, it seems less surprising that Snow approached the problem of inconsistent results during the early days of ether inhalation in London as a specialist in respiration medicine with an advanced facility in chemistry. More than three years before he witnessed Robinson’s procedures at

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\item \textsuperscript{35} Snow, “Arsenic as a preservative of dead bodies,” \textit{Lancet} 1 (10 November 1838): 264.
\item \textsuperscript{35a} "Westminster Medical Society," \textit{LMG} 24 (6 April 1839): 60--61; meeting of 30 March.
\item \textsuperscript{36} Snow, "On the pathological effects of atmospheres vitiated by carbonic acid gas, and by a diminution of the due proportion of oxygen," \textit{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 18½ oxygen, 81½ nitrogen in every 100 parts, the oxygen being reduced 2½ 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.
\end{itemize}
the end of December 1846, Snow had experimented with the administration of ether as a "diapnetic," a term he coined for a family of agents whose common medicinal and chemical properties he believed would enhance respiration.\footnote{Snow, "Circulation in the capillary blood-vessels," \textit{LMG} 31 (3 March 1843): 813.} That is, he was already familiar with the properties and behavior of ether from experiments he had undertaken in 1843 to assess its capacity to promote respiration when inhaled. It only took Snow a fortnight to propose a solution because he knew 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: 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."\footnote{Snow, "On the inhalation of the vapour of ether," \textit{LMG} 39 (19 March 1847): 498.} As we have seen, he used the remainder of January 1847 to investigate the deductive implications (physico-chemically, technologically, and finally clinically) of this hypothesis. Then, for the next eight weeks, his practice was an exemplar of John Herschel's dictum, "that the successful process of scientific enquiry demands continually the alternative use of both the \textit{inductive} and \textit{deductive} method."\footnote{John F. W. Herschel, \textit{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 so quick to develop an efficient ether inhaler. For example, see David A. E. Shephard, "John Snow and research," \textit{Canadian Journal of Anaesthesia} 36 (1989): 224-41; Rod K. Calverley, "An early ether vaporizer designed by John Snow," in \textit{The History of Anesthesia, Third International Symposium, Proceedings} (Park Ridge, IL: Wood Library-Museum, 1992); Shephard, John Snow, \textit{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., \textit{Cholera, Chloroform, and the Science of Medicine}.}
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, 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’ classification), 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.

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 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.


Snow’s modified ether vaporizer (Mark II)
First used by Snow in surgical operations on 4 February 1847.

Figure adapted from illustration in LMG 39 (19 March 1847): 501.
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 Caesar 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 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. 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. From that day forward, Snow was de facto 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 vaporizer and procedure. As Mr. Cutler purposely inserted the sound

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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 vapor,” 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 (1 February 1847): 361.

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Extant Snow Ether Vaporizers

The late Richard Ellis proposed a classification for what he regarded as four distinctly different models, or to use his expression, “marks,” of Snow’s ether vaporizers; he only published an abstract in History of Anaesthesia Society, Proceedings 8b (June 1990): 81. The classification was based solely on descriptions in Snow’s publications; Ellis never saw either of the known original Snow ether vaporizers housed at the Museum of the Royal College of Physicians (London, U.K.) and at the Wood Library-Museum (Park Ridge, Illinois, USA).

Henry Connor and David Zuck have examined the model housed at the Royal College of Physicians, which bears the inscription, “Ferguson/21 Giltspur St/London.” The chamber measures 113 mm (4.4 in.) in diameter, 60 mm (2.4 in.) in height. This apparatus contains the three alterations to the prototype that distinguish the modified vaporizer chamber (capped air inlet, capped ether port, and two-way valve) which Ellis labelled “Mark II.” For a complete set of internal and external dimensions, photographs, and detailed analysis of this model, carrying case, and a thermo-etherometer, see H. Connor and D. Zuck, “A very rare ether vaporizer designed by John Snow,” History of Anaesthesia Society, Proceedings 41 (2009): 105-22.

With the kind cooperation of Dr. George Bause, Connor and Zuck secured measurements and photographs of the Wood Library-Museum apparatus. It also has all the hallmarks of the modified (Mark II) vaporizer. It would appear that there are no extant examples of the prototype vaporizer.
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 still fully sensible, but “rather out of breath.”

Snow must have been puzzled. This had not happened in the previous seven operations. He checked the apparatus, and observed that he had forgotten to remove the cap on the inlet pipe to the ether chamber. That was why, 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 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.”

How could Snow have made such an elemen-

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
tary mistake, given his earlier successes? One possibility is that he had not incorporated into his routine another of Ferguson’s modifications to the prototype vaporizer – a screw cap on the air intake coil encircling the outside of the ether chamber. The intake coil of the prototype was uncapped. Ferguson had also added a separate aperture for pouring ether into the chamber of the modified vaporizer. Although Snow and the journals only mention the latter when describing the new apparatus he introduced on the 4th of February, it seems likely that Ferguson made all three modifications at the same time.

Two days later, the 13th of February, at the Westminster Medical Society, Snow read a paper on ether vapor and its use in surgical operations. He began with the pharmacological effects of ether inhalation. The ether uptake table he was still using at the time indicates that in any saturated volume of air-ether mixture, the ether vapour displaced a certain quantity of air,

incorrect. The reporter for LMG accepted Johnson’s explanation that the ether was discontinued because of the bronchitis; “Westminster Medical Society,” LMG 39 (26 February 1847): 384, fn.

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); Ellis, “Inhalers of Dr. John Snow,” History of Anesthesia Society, Proceedings 8b (1990): 81. For the dates of Snow’s four ether inhalers, see H. Connor and D. Zuck, “A very rare ether vaporizer designed by John Snow,” History of Anaesthesia Society, Proceedings 41 (2009): 105-22.

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 was still unaware that his table was 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. "Such, however, was not the case," wrote the person taking minutes, "for he [Snow] 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. 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 supports our argument that consilient factors partly explain 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 terminal capillaries in the tissues, 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 vaporizer 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

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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.
research. Precisely what he did is unclear, since the minutes for the 20th of February record only that Snow said then that he "had completed some experiments" since reading his paper the week before.47 But four years later, he wrote 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 those 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 experimen-

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.
tation he undertook, for the secretary recorded him as stating that “these circumstances he considered confirmed the explanation of the modus operandi of ether which he had previously given [in the paper read on the 13th].” 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.”

Snow, however, was still unsatisfied with how his modified vaporizer performed. In order for his apparatus to work as designed, and for him to know the precise dosage of ether vapor actually administered, the patient’s mouth and nostrils must be completely closed to outside air. The original Tracy mouthpiece,

52. “Westminster Medical Society,” *LMG* 39 (26 February 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 [followed by note citing *LMG* 39: 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 (26 February 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.”
and Snow’s modification described in mid-January 1847, was similar to others “in ordinary use” — most likely the tube and valves developed by John Read — and, like them, required a separate nose clip, which some patients found disagreeable. S4 Tracy soon developed a new mouthpiece that enclosed the nostrils. S5 Some time in February, Snow decided to employ the modified Tracy mouthpiece — a combination pad of flannel, morocco leather, and rubber. Snow did make a telling modification, 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.” S6 He had not forgotten his experiments on arsenic toxicity in cadavers and candles while a medical student at the Hunt erian. 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 when the modified (Mark II) vaporizer included the original Tracy mouthpiece.

It had been Snow’s habit for several years to submit a copy of each paper he read directly to the London Medical Gazette, 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 Medi-


500.
cal 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 Green Linnet — the common name in Yorkshire for a Greenfinch which was 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. 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 dissolved in the blood — as distinct from asphyxia, where the recovery would have been almost immediate under these conditions.59 After this demonstration, the Society 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

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). Nelson notes about 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.
of ether vapour and of air,” an impossibility if one employed glass inhalers with sponges to absorb the liquid ether.60

On the 1st of March, the Pharmaceutical Journal published a very belated description of Snow’s prototype vaporizer — the one already superceded by the addition of a two-way tap — and alluded to “a remarkable coincidence” between Snow’s design and an illustration of “Mr. Jeffery’s [sic] Apparatus.”61 Snow fired off a blistering letter to the editor: “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. “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 Snow’s essay on “Inhalation of the vapour of ether,” in two parts, the first on March 19. Like Beethoven in the opening bars of his Fifth Symphony, Snow immediately

60. Ibid.
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
hammered out his principal theme. "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 the control of the administrator. 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 pharmacodynamics). In his view, most failures with ether inhalation were due to the fact that patients had been breathing overly diluted ether vapor, not to constitutional factors in those patients. Snow concluded the opening paragraph with a reductionistic assertion that justified his physico-chemical approach: "I believe that no sentient being is proof against its influence."

Most of part one consisted of Snow's review of his early reasoning and physico-chemical experimentation with ether inhalation. 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 being accurate. But instead of printing a corrected table in the article, Snow had prepared a new table on a different plan, showing how much washed ether to pour into his vaporizer to achieve the desired ether vapor/air ratio at different temperatures, which

\[ 127 \text{ minims of washed ether in a vaporizer placed in a water bath at } 70^\circ \text{ yields } 115.5 \text{ cubic inches of ether vapor per 100 cubic inches of air.} \]

he believed was more accessible to the average practitioner "unaccustomed for a long period to arithmetical calculations" ("IVE," 499). He explained how the modified (Mark II) vaporizer 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, complimented Ferguson on his skillful contrivances, and mentioned his preference for the latest Tracy mouthpiece.

Part two, in the following number published on 26 March, featured Snow’s description of the procedure he used in ether administrations and his clinical observations to date of patients undergoing surgical operations. One thing was paramount, as indicated at the end of part one — “the shorter the process the better” ("IVE," 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. 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 had concluded, based on clinical epidemiological observations, that the cause was due to a minor fault in his apparatus. That is, among his patients to date, children “inhaled more easily than the adults generally did . . . [and] were more quickly affected, generally becoming insensible in

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Snow’s modified (Mark II) ether vaporizer with the modified Tracy mouthpiece


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### TABLE OF THE QUANTITY OF THE VAPOUR OF ETHER IN ONE HUNDRED CUBIC INCHES OF AIR, Saturated with it at various temperatures.

**By John Snow, M.D.**

<table>
<thead>
<tr>
<th>Temp. Fahr.</th>
<th>Cubic Inches Ether</th>
<th>Weight in Ends Ether</th>
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<td>24.3</td>
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<td>18.1</td>
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</tr>
<tr>
<td>200°</td>
<td>2.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

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Snow’s modified (Mark II) ether vaporizer with the modified Tracy mouthpiece


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**PharmJ** (1 April 1847): 474.
less than two minutes, and always without any of the struggling which sometimes occurred in adults” (“IVE,” 540). Since he used the same vaporizer on children and adults, the only difference he could imagine was that “the tubes were wider in proportion for children than adults” (“IVE,” 540). Shortly before submitting the manuscript, he had disassembled one of his apparatus and found, to his dismay, that the internal width of the breathing 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 . . .” (“IVE,” 541). The editors permitted him to add a footnote to the effect that the wider tubes had worked as expected.

Snow the technologist then moved off in a surprising direction. “With respect to the psychological phenomena produced by ether,

I have observed that consciousness seems to be lost before the sensibility to pain, and if an operation is commenced [i]n this stage, the patient will flinch, and even utter cries, and give expressions of pain, but will not remember it, and will assert that he has felt none. Metaphysicians have distinguished between sensibility and perception — between mere sensation and the consciousness or knowledge of that sensation, though the two functions have, as they supposed, always been combined. Ether seems to decompose mental phenomena as galvanism decomposes chemical compounds, allowing us to analyse them, and

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. “The apparatus was placed in water at 70°, and he began to inhale through the wide tubes, three quarters of an inch in diameter, which Dr. Snow has now got to his apparatus . . . ,” in “St. George’s Hospital,” Lancet 1 (3 April 1847): 368.
showing that the metaphysicians were right. During the recovery of the patient, consciousness, which first departed generally returns first, and the curious phenomenon is witnessed of a patient talking, often quite rationally, about the most indifferent matters, whilst his body is being cut or stitched by the surgeon. I have never seen this insensibility to pain during the conscious state except where consciousness had been previously suspended ("IVE," 541).

He continued with a description of the recovery period, and wrote that "it was my intention to make some remarks on the probable way in which ether acts in suspending sensibility; but, as what I have already written is probably sufficient for one article, I will reserve that part of the subject for a future communication . . ." ("IVE," 541). He never did return to it, however. Little wonder, since it was barely a generation since William Lawrence’s introductory course on physiology at the Royal College of Surgeons had been indicted by the Attorney General and declared blasphemous by the Court of Chancery. Unlike in secular France, the early Victorian era was not the occasion for a young physician, ambitious to become anaesthetist to the aristocracy, to start mechanistically decomposing the mysteries of the brain.

* * *

Snow concluded part two of his extended article on the "Inhalation of the vapour of ether" with the observation "that I am inclined to look upon the new application of ether as the most valuable discovery in medical

68a. Adrian Desmond and James Moore, *Darwin* (1991; New York: Warner Books, 1992), 253. Snow’s mechanistic and transformationist leanings may stem from his early association with John Epps; see Ibid., 238. Snow took four courses from Epps at the Hunterian School of Medicine, and it was Epps who introduced him to the Westminster Medical Society; Vinten-Johansen, et al., *Cholera, Chloroform, and the Science of Medicine*, 61, 63, 70.
science since that of vaccination” (“IVE,” 541). If so, he had done more than anyone else to make that happen. In the first month of 1847, Snow 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 effective vaporizer, by virtue of which he could select and control the amount of ether inhaled by patients in three surgical operations. In subsequent weeks, Snow had continued this three-stage feedback loop — responding to any clinical problems encountered in fifteen additional operations at St. George’s Hospital by making a series of empirical adjustments in his apparatus, engaging in additional experimentation, and presenting his findings at the Westminster Medical Society. The two-part article printed in the London Medical Gazette during the second half of March made public everything he had done since the beginning of the year.

The effect was then, and is still, indisputable: in a matter of three months, Snow had established the practice of general anesthesia by ether inhalation on a sound scientific footing, whereas many of his contemporaries had approached it solely as an empirical art.69 By comparison, James Robinson’s Treatise on ether, which had appeared in late February, was anecdotal and self-congratulatory. Their medical colleagues perceived the difference. After publication of part two of “Inhalation of the vapour of ether” at the end of March 1847, John Snow was the acknowledged medical authority in London on the inhalation of ether.

Snow did not rest on these laurels. He demonstrated a portable version of his modified (Mark II) vaporizer at the April 3rd meeting of the Westminster Medical Society. The chamber was about an inch and a half smaller in diameter than the full-sized model, but had the same depth. While the chamber interior was essentially unchanged, Snow had asked Ferguson to

replace the two-way stop-cock with two valves and a ferrule near the mouthpiece. The breathing tube and valves were sized at five-eighths of an inch — an oddity, given the augmentation he had recently introduced to the larger model, and could be why Snow showed no enthusiasm for this pocket-sized vaporizer hereafter and no journal bothered to publish an engraving.

Nevertheless, Snow’s decision to replace the stop-cock on the Mark II vaporizer chamber with valves near the mouthpiece of the pocket version indicates that the compact model was part of a continuous and evolving process to develop an ideal ether apparatus. Whereas the stop-cock on the modified vaporizer had given Snow greater control of the precise ether/air dosage he was administering, it could be awkward to fiddle with it with one hand while holding the mouthpiece in place with the other. Moreover, the Tracy mouthpiece was fundamentally problematical because it did not cover the nostrils and had to be supplemented with a nose clip; some patients instinctively attempted to breathe via the nostrils whilst anesthetized, to the degree that they pulled ambient air into the lungs via their lachrymal ducts.

So Snow remained in pursuit of improvements in the breathing circuits to his apparatus. On 3 May he used a request from Robert Liston to administer ether for him at University College Hospital to introduce yet another modification — a face-piece designed by Francis Sibson of Nottingham. Better, but still cumbersome. He employed it in seven surgical operations at St. George’s and four at University College Hospitals in the following five weeks before unveiling what would become his definitive version: a variation of Sibson’s

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70. Snow mentioned at this demonstration on 3 April that the new design was solely undertaken at the request of some Society members who wanted a portable vaporizer instead of the larger version. “He did not intend it to supersede the latter”; “Westminster Medical Society,” *Lancet* 1 (10 April 1847): 388-89. Ellis classified the pocket vaporizer as Mark III.


72. Ibid., 113.


The Sibson Face-piece

1. Nose and mouth-piece — a funnel fitting, as closely as possible, over the nose and mouth, made of Macintosh, lined with oiled silk. The thumb compresses it over the nose, the fingers, if needful, over the chin.

2. Vulcanized India-rubber strap to keep the nose and mouth-piece in its place by means of

3. A buckle.

4, 5. Two inches of vulcanized India-rubber tube attached to the mouth-piece.

6. Brass tube with valves. The outer valve is almost poised by a lever; the inner valve is closed by a weak spring.

7. Eighteen inches of flexible tube.

face-piece, including the addition of two swinging valves, a fixed one with a direct connection to the ether chamber, and an expiratory valve that could be adjusted to allow inhalation of ambient air. The swing valves meant he could dispense with Tracy’s ball-valve assembly on the breathing tube.

In June Ferguson produced the final version of the modified Sibson face-piece and the first version of what, with a few more modifications during the coming weeks, became the definitive Snow ether vaporizer. It consisted of two main parts: (a) the water bath, a box of japanned tin “about the size of a thick octavo volume” (approximately 6” x 9”), half of which served as storage for the elastic breathing tube and facepieces when the apparatus was not in use; and (b) the vaporizing chamber of thin tinned brass, with a spiral attached to the underside of the lid, fitting closely into the water bath and attached to it by metal clasps. In use it could be moved to the center of the water bath. In the center of the far side of the lid of the ether chamber was an opening for pouring the ether in or out, into which could be screwed a short brass tube which served as the air inlet; its purpose was to avoid “the trifling loss of ether by evaporation.” Ether vapor, being heavier than air, would not rise up the tube; and the tube presented less resistance to inhaling than a valve. In the center of the lid was another opening, into which could be screwed the mount of the three feet long elastic breathing tube, at the other end of which was a ferule for the attachment of the face-piece with its inspiratory and expiratory valves.

This simplified apparatus retained all the basic principles, while incorporating all the step by step improvements which Snow

74. “St. George’s Hospital,” *Lancet* 2 (10 July 1847): 35. Snow first used a modified Sibson face mask on 10 June, then again on 17 June.
had made between the beginning of February and the end of May. It was an extremely effective apparatus. Although Snow gave no indication that he was aware of the concept of dead space, by incorporating the valves into the face-piece he had reduced the dead space of the vaporizer to the volume of the gases between the inside the face-piece and the face, which was very small indeed.\textsuperscript{75a}

* * *

Earlier in the month of May 1847, on Monday the 3\textsuperscript{rd}, the Royal Academy of Arts opened its annual exhibition in the East Wing of the National Gallery, Trafalgar Square, London (I on the map at the end of the essay). The painter, Thomas Jones Barker, recently settled in the metropolis, had three works on display, one of them entitled “Dr. Snow.” John Snow, M.D. served as family practitioner to the Barkers in London, and it is nearly certain that the portrait on display was of him. For Barker would have honored the physician who was increasingly recognized as the premier anaesthetist in London, not just a diligent family doctor.\textsuperscript{76}

In addition to refining his ether apparatus, Snow had used the late spring and summer to clarify and popularize his message that ether could be administered safely via his apparatus and method. Additional evidence that Snow was a rising star occurred on Wednesday 12 May. By invitation of the Council of the prestigious United Service Institute, located near Whitehall in Middle Scotland Yard, he delivered a lecture on the “practical points connected with the admin-


\textsuperscript{76} David Zuck, “Snow, Empson and the Barkers of Bath,” Anaesthesia 56 (March 2001): 227-30. Thomas Jones Barker (1815-1882) was the son of a celebrated artist, Thomas Barker of Bath. Thomas Barker was a friend of John Snow’s uncle, Charles Empson of Bath. It is likely that Empson recommended Snow as a prospective family doctor when Thomas Jones Barker moved to London.
istration of ether to its medical members. He started with a brief history of the introduction of general anaesthesia by inhalation, then moved on to a practical demonstration of the effects of ether inhalation on three varieties of the living — a thrush, a guinea pig, and goldfish. He accidentally exposed the thrush to ether vapor for longer than intended, but quick-wittedly drew a lesson from his mistake. The thrush was dead; "it is a result I did not intend, and it has arisen from my going on with the lecture, and looking at my notes, instead of directing my whole attention to the animal." Let this mistake be a warning. It "shows the power of the agent, but it does not follow that there is any danger giving the vapour to a patient; for of course the medical man directs the whole of his attention to what he is doing. . . . Besides, the vapour acts much less rapidly on human beings and on quadrupeds than on birds," which he thereafter demonstrated with the guinea pig.

He continued with an explanation of the technology of his current apparatus (the Mark II modified vaporizer), the crucial importance of the uptake table, which he had modified to simplify the calculation of how much liquid ether was required to achieve the desired amount of vapor; he explained why a vaporizer constructed of metal was superior to glass apparatus; showed why the breathing tube should be elastic and of sufficient internal diameter so the patient’s breathing was unobstructed; lauded Sibson’s face-piece (which he was still using) as superior to various face- and mouthpieces on the market; and discussed the progressive stages of etherization, how the administrator could establish the transition among them and monitor the dosage of ether vapor required to maintain insensibility to the conclusion of the operation.

Then he moved to the particular circumstances in which an Army or Navy doctor might find himself. Knowing the reputation of soldiers and sailors for hard drinking, he remarked that he had etherized a number

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<tr>
<th>Temp. Fahr.</th>
<th>Cubic inches of vapour</th>
<th>Minims of Ether</th>
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<td>90°</td>
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of habitual hard drinkers, and not found any difficulty. Should the doctor have no medical assistance, “as might happen in a small brig or schooner,” he must give the ether to the patient himself, having first got everything ready for the operation, and placed the patient in the correct position. While giving the ether he must direct his whole attention to it, but once the patient was insensible he should discontinue it, and direct his whole attention to the operation. A great number of surgical operations do not last more than three minutes, and the patient will remain insensible for this period. Snow also explained how to render common sulphuric ether fit for inhalation if washed ether was unavailable.  

He pointed out that the benefit of pain relief during operations on the seriously wounded brought with it relief from “the shock to the system from which it is sometimes unable to recover.” It avoids the faintness that arises during the operation, “more from pain than loss of blood,” and he quoted supporting statistics from St. George’s Hospital. Then he discussed one of the problems with which the Forces medical men are peculiarly faced — malingering. Reports from the Continent had described the value of ether in resolving these uncertainties. A deformity of the spine had disappeared when the muscles relaxed under ether, and conversely, suspected feigned stiffness of the hip joint was proved to be due to ankylosis of the joint. 

Snow had provided a comprehensive guide to the administration of ether, the apparatus, the signs of anaesthesia, and the care of the patient, specially directed to the needs of medical men in Her Majesty’s Forces.

The following day, Thursday 13 May, Snow administered ether at St. George’s Hospital whilst Mr. Hawkins performed a delicate and extended operation to remove necrosis from a teen-ager’s humerus, a procedure that would have been unimaginable a half year previously. Snow returned to that operating theatre every Thursday thereafter (with two exceptions, when no

79. Ibid., 552-53.
80. Ibid., 553.
operations were scheduled) until the summer recess in September. In all, he was the anesthetist during fifty-two scheduled surgical cases at St. Thomas between 28 January and 2 September (in addition, the house-surgeon administered ether using an apparatus like Snow’s in four emergency cases). University College Hospital had a larger surgical caseload, with non-emergency operations scheduled several days each week. Snow administered ether during twenty-three operations between 3 May and 8 September, all but one for Robert Liston and Richard Quain.81

Snow used the September recess to complete and submit the manuscript of a monograph incorporating all principles derived from his experience and experiments. It was based on the United Service Institute lecture, minus battlefield examples — “the remarks ... are confined strictly to the practical part of the subject” of etherization, for the benefit of students and practicing members of the medical profession.82 He described the principle underlying the design of the Mark IV vaporizer he’d been using for the last three months; explained why he considered it essential to use a wide breathing tube; underscored the advantages of a facepiece with adjustable valves compared to a mouthpiece that did not cover the nostrils; duplicated the simplified and eminently pragmatic ether/air table he had displayed to military surgeons; and (in an appendix) noted the very few circumstances when, in his view, administering ether vapor via a sponge and per rectum was superior to employing a good apparatus. Snow’s monograph also featured advice on the process of etherizing patients of various ages and physical constitutions, from the water temperature

81. Snow, On the Inhalation of the Vapour of Ether in Surgical Operations (London: Churchill, 1847): 56-71. Snow refused to patent the design of his ether vaporizers and insisted that no instrument maker restrict others from making it. By September 1847, four firms in addition to Ferguson were constructing Snow’s ultimate (Mark IV) vaporizer; Ibid., 23. The list price of the eighty-eight page monograph was 3 shillings, 6 pence.

82. Ibid., vi, v.
in the apparatus, the amount of liquid ether required, how to position patients depending on the operation, signs indicating when to begin an operation and when to increase or decrease the proportion of ether vapor administered, as well as the recovery process.

This book did contain a refinement of his previous writings and presentations: an explicit, five-degree division of the stages and signs of etherization. This was a practical treatise, and Snow decided it was appropriate to synthesize his accumulated clinical experience (often described previously in the medical journals) into a set of guidelines he considered virtually foolproof if the administrator knew and carefully monitored the strength of the vapor received by the patient. He made no claim to originality in doing so; Flourens, for example, had devised a similar division after conducting experiments on dogs. Snow just thought his division into five degrees, based on clinical observations during surgical procedures on humans, was pragmatically more useful to inexperienced etherizers.83

Whereas Snow’s discussion of five degrees of etherization in the monograph feature the anesthetic potential and dangers in administering the vapor of ether, the preface hints at what he did next. He wrote there that he considered "the relations of etherization to medical science and physiology . . . a tempting field for research."84 The start of medical school lectures and hospital rounds in October brought a resumption of scheduled surgical operations which would require Snow’s services. Each time he administered ether, Snow augmented his notes on the clinical epidemiology of this narcotic agent. Thereafter he correlated his clinical findings with the results of physico-chemical and laboratory investigations conducted at home (and, perhaps, in the laboratory of the Aldersgate School of Medicine near Bart’s where he was lecturer in forensic

83. Ibid., 13-14. For a tabular synthesis and additional discussion of Snow’s five degrees, see Vinten-Johansen, et al., Cholera, Chloroform, and the Science of Medicine, 126-27.
84. Snow, Vapour of Ether, v.
medicine). That is, he resumed the research undertaken in January 1847 into the physiological explanations underlying the capacity of ether vapor to produce insensibility to pain.

When James Young Simpson proposed in November 1847 that chloroform was "more efficient than sulphuric ether" as an "anaesthetic agent," Snow immediately repeated a truncated version of the research process he had undertaken with ether during the first three months of the year, and reported his initial findings, including a chloroform/air uptake table, to the Westminster Medical Society on 20 November. By then, he had already administered chloroform in a surgical operation, using his ether vaporizer. By the end of the year he had in mind a design for a new apparatus for administering chloroform. From that point forward, he always referred to five degrees of narcotism and set an agenda for research into the pharmacology of narcotic agents that he pursued until his death in 1858.

The two faces of the Roman god, Janus, is sometimes used as a metaphor for history. One face looks backward. It was Snow's good fortune that the discovery of ether inhalation by others complemented 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, a veritable *annus mirabilis*, was made possible by a fortuitous immersion in relevant basic sciences, previous clinical and research experience in respiratory medicine, and an extraordinary ability to apply knowledge from such disparate fields to a new and complex problem — a concurrence labelled consilience in Snow’s time by William Whewell, in ours by Edward O. Wilson.

87. Snow preferred narcotic to anaesthetic when discussing agents for inducing insensibility because the former term was more inclusive from a scientific-medical perspective. The word, anaesthesia, or its variants never appear in his writings, as anyone may attest by doing keyword searches via <http://johnsnow.matrix.msu.edu/search.php>.
A University College (formerly North London) Hospital.
B Robinson’s house, 7 (now 14) Gower Street.
C Exeter Hall, Strand.
D St. George’s Hospital.
E Hunterian School of Medicine.
F Soho Square and surroundings.
G Ferguson’s instrument shop on Giltspur St., across from St. Bartholomew’s Hospital.
H United Service Institution, Middle Scotland Yard.
I Royal Academy of Arts, National Gallery, Trafalgar Square.

Adaptation of “an outline plan of London” attached to the 24 September 1836 number of the Lancet.
This map was folded and then glued to the issue.
The original available to us was marred by some blurring due to age and deterioration of the paper.