VII. *On the Atmosphere as a Vehicle of Sound.*

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§ 1. *Introduction.*

The cloud produced by the puff of a locomotive can quench the rays of the noonday sun; it is not therefore surprising that in dense fogs our most powerful coast-lights, including even the electric light, should become useless to the mariner.

Disastrous shipwrecks are the consequence. During the last ten years no less than two hundred and seventy-three vessels have been reported as totally lost on our own coasts in fog or thick weather. The loss, I believe, has been far greater on the American seaboard, where trade is more eager and fogs more frequent than they are here. No wonder, then, that earnest efforts should have been made to find a substitute for light in sound-signals, powerful enough to give warning and guidance to mariners while still at a safe distance from the shore.

Such signals have been established to some extent upon our own coasts, and to a still greater extent along the coasts of Canada and the United States. But the evidence as to their value and performance is of the most conflicting character, and no investigation sufficiently thorough to clear up the uncertainty has hitherto been made. In fact, while the *velocity* of sound has formed the subject of refined and repeated experiment by the ablest philosophers, since the publication of Dr. Derham's celebrated paper in the Philosophical Transactions for 1708, no systematic inquiry has, to my knowledge, been made into the causes which affect the *intensity* of sound in the atmosphere.

As an attempt to fill the blank here indicated, I beg to submit to the Royal Society some account of an investigation on fog-signals recently carried out at the instance of, and in conjunction with, the Elder Brethren of the Trinity House. Soon after my return from America I was requested, as the scientific adviser to the Corporation, to undertake the direction of this inquiry. I entered upon it inspired by duty rather than hope, for I feared that the observations would be tedious and the scientific results uncertain. But the study of any natural problem, if only steadfastly pursued, is sure in the end to reward the inquirer. And so in the present instance, after some preliminary groping,

* These dates apply to the chief points of the paper in its complete state, including the experiments on mixtures of gases and vapours and on differently heated air. A copious preliminary account, embracing the observations made at sea and the conclusions founded thereon, was read on January 15 (Proceedings, vol. xxii. p. 58). The experiments on the effect of fumes, &c. (§ 13) were described before the Society on May 21. In rearranging the paper with the view of throwing certain details into an appendix, these last experiments have been embodied in the original paper.

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light began to dawn upon the subject, revealing many old errors and some novel truths. As the results had a scientific as well as a practical bearing, I requested permission to lay them before the Royal Society, the prompt and cordial consent of the Elder Brethren being the response.

§ 2. *Condition of the Question.*

A few extracts and references will suffice to show the state of the question when this inquiry began. "DERHAM," says Sir JOHN HERSCHEL, "found that fogs and falling rain, but more especially snow, tend powerfully to obstruct the propagation of sound, and that the same effect was produced by a coating of fresh-fallen snow on the ground, though when glazed and hardened at the surface by freezing it had no such influence"*.

In a letter addressed to the President of the Board of Trade in 1863†, Dr. ROBINSON, of Armagh, thus summarizes our knowledge of fog-signals:—"Nearly all that is known about fog-signals is to be found in the Report on Lights and Beacons; and of it much is little better than conjecture. Its substance is as follows:—

"Light is scarcely available for this purpose. Blue lights are used in the Hooghly; but it is not stated at what distance they are visible in fog: their glare may be seen further than their flame‡. It might, however, be desirable to ascertain how far the electric light or its flash can be traced§.

"Sound is the only known means really effective; but about it testimonies are conflicting, and there is scarcely one fact relating to its use as a signal which can be considered as established. Even the most important of all, the distance at which it ceases to be heard, is undecided.

"Up to the present time all signal-sounds have been made in air, though this medium has grave disadvantages: its own currents interfere with the sound-waves, so that a gun or bell which is heard several miles *down* the wind is inaudible more than a few furlongs *up* it. A still greater evil is that it is least effective when most needed; for fog is a powerful damper of sound."

Dr. ROBINSON here expresses the universally prevalent opinion, and he then assigns the theoretic cause. Fog, he says, "is a mixture of air and globules of water, and at each of the innumerable surfaces where these two touch, a portion of the vibration is reflected and lost‖. . . . . Snow produces a similar effect, and one still more injurious."

Reflection being thus considered to take place at the surfaces of the suspended particles, it followed that the greater the number of particles, or, in other words, the denser the fog, the more injurious would be its action upon sound. Hence optical transparency came to be considered as a measure of acoustic transparency. On this point Dr. ROBINSON, in the letter referred to, expresses himself thus:—"At the outset, it is obvious that, to

* Essay on Sound, par. 21.

† Report of the British Association for 1863, p. 105.

‡ A very sagacious remark: see letters in the Appendix.

§ Powerful electric lights have been since established and found ineffectual.

‖ This is also Sir JOHN HERSCHEL's way of regarding the subject. Essay on Sound, par. 38.

make experiments *comparable*, we must have some measure of the fog's power of stopping sound, without attending to which the most anomalous results may be expected. It seems probable that this will bear some simple relation to its opacity to light, and that the distance at which a given object, as a flag or pole, disappears may be taken as the measure." "Still clear air" is regarded in this letter as the best vehicle of sound, the alleged action of fogs, rain, and snow being ascribed to their rendering the atmosphere "a discontinuous medium."

To Mr. ALEXANDER BEAZELEY we are indebted for an extremely useful summary of existing knowledge regarding fog-signals*. He classifies the various instruments hitherto employed, and gives some account of their performance. As regards the action of fog upon sound, the statements made in the body of his papers agree with those just quoted from Dr. ROBINSON. "Fogs," he says, "have a remarkable power of deadening sound, and act in this respect so irregularly, that experiments made during clear weather have little or no practical value, except as mere competitive trials of different instruments."

In the discussion which followed the reading of Mr. BEAZELEY'S paper at the Institution of Civil Engineers, Dr. GLADSTONE, who was a member of the Commission on Lights and Beacons, is reported to have said, "A difficulty in the use of sound was this, that fogs deadened sound very materially; but the evidence was very contradictory on that point. In a fog on land it was difficult to hear the passing of carriages or noises at a short distance; and so in a fog at sea these signals found a difficulty in penetrating the fog against which they are intended to be a protection."

On the same occasion Mr. JAMES N. DOUGLASS, the Engineer of the Trinity House, to whose ability as an observer I am able to bear strong testimony, stated that in his experience "he had found but little difference in the travelling of sound in foggy or in clear weather. He had distinctly heard in a fog, at the Small's Rock in the Bristol Channel, guns fired at Milford, twenty-five miles off." Mr. BEAZELEY had also heard the Lundy-Island gun "at Hartland Point, a distance of ten miles, during dense fog;" so that, in winding up his paper, he admitted "that the subject appeared to be very little known, and that the more it was looked into the more apparent became the fact that the evidence as to the action of fog upon sound is extremely conflicting."

In a paper presented to the Literary and Philosophical Society of Manchester on the 16th of December, 1873, Professor OSBORNE REYNOLDS affirms the prevalent doctrine with great distinctness, and makes a very ingenious attempt to explain it. "That sound," says Professor REYNOLDS, "does not readily penetrate a fog is a matter of common observation. The bells and horns of ships are not heard so far during fogs as when the weather is clear. In a London fog the noise of the wheels is much diminished, so that they seem to be at a distance when really close by."

My knowledge does not inform me of the existence of any other source for these

* Proceedings of the Institution of Civil Engineers, March 14, 1871; and Lecture at the United-Service Institution, May 24, 1872.

opinions regarding the deadening power of fog than the paper of DERHAM already referred to. In consequence of their *à priori* probability, his conclusions seem to have been transmitted unquestioned from generation to generation of scientific men.

§ 3. *Instruments and Observations.*

These extracts and references sufficiently indicate the uncertain state of the question when, on the 19th of May, 1873, this inquiry began. The South Foreland, near Dover, was chosen as the signal-station, steam-power having been already established there to work two powerful magneto-electric lights. The observations for the most part were made afloat, one of the yachts of the Trinity Corporation being usually employed for this purpose. Two stations had been established, the one at the top, the other at the bottom of the South-Foreland Cliff; and at each of them trumpets and air- and steam-whistles of great size were mounted. The whistles first employed were of English manufacture; but intelligence having been received regarding a large United-States whistle, and also a Canadian whistle, of great reputed power, the Elder Brethren had them subsequently added to the list.

On the 8th of October another instrument, which has played a specially important part in these observations, was introducd. During my recent visit to the United States, I was favoured by an introduction to General WOODRUFF by Professor JOSEPH HENRY, of Washington. Professor HENRY is Chairman of the Lighthouse Board, and General WOODRUFF is engineer in charge of two of the Lighthouse districts. I accompanied General WOODRÜFF to the establishment at Staten Island, and afterwards to Sandy Hook, with the express intention of observing the performance of a steam-syren which, under the auspices of Professor HENRY, has been introduced into the lighthouse system of the United States. Such experiments as were possible to make under the circumstances were made; and I carried home with me a somewhat vivid remembrance of the mechanical effect of the sound upon my ears and body generally. Hence my desire to see the syren tried at the South Foreland. The formal expression of this desire was anticipated by the Elder Brethren, while their wishes were in turn anticipated by the courteous kindness of the Lighthouse Board at Washington. Informed by Major ELLIOTT, of the United States Army, that our experiments had begun, the Board forwarded to the Corporation, for trial, the instrument now mounted at the South Foreland.

In the steam-syren patented by Mr. BROWN, of New York, a fixed disk and a rotating disk are employed as in the ordinary syren, radial slits being cut in both disks instead of circular apertures. One disk is fixed vertically across the throat of a conical trumpet $16\frac{1}{2}$ feet long, 5 inches in diameter where the disk crosses it, and gradually opening out till at the other extremity it reaches a diameter of 2 feet 3 inches. Behind the fixed disk is the rotating one, which is driven by separate mechanism. The trumpet is mounted on a boiler. In our experiments steam of 70 lbs. pressure has for the most part been employed. Just as in the ordinary syren, when the radial slits of the two disks coincide, and then only, a strong puff of steam escapes. Sound-waves of great intensity

are thus sent through the air, the pitch of the note produced depending on the velocity of rotation.

To the syren, trumpets, and whistles were added three guns—an 18-pounder, a $5\frac{1}{2}$-inch howitzer, and a 13-inch mortar. In our summer experiments all three were fired; but the howitzer having shown itself superior to the other guns it was chosen in our autumn experiments as not only a fair but a favourable representative of this form of signal. The charges fired were for the most part those now employed at Holyhead, Lundy Island, and the Kish light-vessel—namely, 3 lbs. of powder. Gongs and bells were not included in this inquiry, because previous observations had clearly proved their inferiority to the trumpets and whistles.

A general knowledge of the instruments employed is thus imparted to the reader; while the Map on Plate XVII. will furnish him with all necessary information as to the position of the localities referred to in the paper.

On the 19th of May the instruments tested were:—

On the top of the cliff:

a. Two brass trumpets or horns, 11 feet 2 inches long, 2 inches in diameter at the mouthpiece, and opening out at the other end to a diameter of $22\frac{1}{2}$ inches. They were provided with vibrating steel reeds 9 inches long, 2 inches wide, and $\frac{1}{4}$ inch thick, and were sounded by air of 18 lbs. pressure.

b. A whistle, shaped like that of a locomotive, 6 inches in diameter, also sounded by air of 18 lbs. pressure.

c. A steam-whistle, 12 inches in diameter, attached to a boiler, and sounded by steam of 64 lbs. pressure.

At the bottom of the cliff:

d. Two trumpets or horns, of the same size and arrangement as those above, and sounded by air of the same pressure.

e. A 6-inch air-whistle, similar to the one above, and sounded by the same means.

The upper instruments were 235 feet above high-water mark, the lower ones 40 feet. A vertical distance of 195 feet, therefore, separated the instruments. A shaft, provided with a series of twelve ladders, led from the one to the other.

The trumpets were constructed by that able mechanician, Mr. Holmes, who had them throughout under his personal superintendence. They were mounted vertically on the reservoir of compressed air; but within about 2 feet of their extremities they were bent at a right angle, so as to present their mouths to the sea (see sketch of horn on Plate XVIII., where the steel reeds are also shown). The aim of their constructor was to distribute the sound equably over an arc of 180°. To effect this, he placed the horizontal parts of the axes of the horns at right angles to each other, the one pointing S.W. by S., and the other S.E. by E., each horn being supposed to cover an arc of 90°.

The 12-inch steam-whistle was constructed by Mr. Baily, of Manchester.

Our first experiments with these instruments were a preliminary discipline rather than an organized effort at discovery. On May 19 we steamed round the Foreland and out

to sea in the axes of the horns. The maximum distance reached by the sound was about three and a half miles*. The wind, however, was high and the sea rough, so that local noises interfered to some extent with our appreciation of the sound.

Mariners express the strength of the wind by a series of numbers extending from 0 = calm to 12 = a hurricane, a little practice in common producing a remarkable unanimity between different observers as regards the force of the wind. Its force on May 19 was 6, and midway between the axes of the two trumpets it blew at right angles to the direction of the sound.

The same instruments on the 20th of May covered a greater range of sound; but not much greater, though the disturbance due to local noises was absent. At 4 miles distance in the axes of the horns they were barely heard, the air at the time being calm, the sea smooth, and all other circumstances exactly those which have been hitherto regarded as most favourable to the transmission of sound. We crept a little further away, and by stretched attention managed to hear at intervals, at a distance of 6 miles, the faintest hum of the horns. A little further out we again halted; but though local noises were absent, and though we listened intently, we heard nothing.

This position, clearly beyond the range of whistles and trumpets, was expressly chosen with the view of making what might be considered a decisive comparative experiment between horns and guns as instruments for fog-signalling. The distinct report of the 12 o'clock gun fired at Dover on the 19th suggested this comparison, and through the prompt courtesy of General Sir A. HORSFORD we were enabled to carry it out. At 12.30 precisely the puff of an 18-pounder, with a 3-lb. charge, was seen at Dover Castle, which was about a mile further off than the South Foreland. Thirty-six seconds afterwards the loud report of the gun was heard, its complete superiority over the trumpets being thus, to all appearance, demonstrated.

We clinched this observation by steaming out to a distance of $8\frac{1}{2}$ miles, where the report of a second gun was well heard by all of us. At a distance of 10 miles the report of a third gun was heard by some of us, and at 9·7 miles the report of a fourth gun was heard by us all.

The result seemed perfectly decisive. Applying the law of inverse squares, the sound of the gun at a distance of 6 miles from the Foreland must have had more than two and a half times the intensity of the sound of the trumpets. It would hardly have been rash under the circumstances to have reported without qualification the superiority of the gun as a fog-signal. No single experiment is, to my knowledge, on record to prove that a sound once predominant would not be always predominant, or that the atmosphere on different days would show preferences to different sounds. On many subsequent occasions, however, the sound of the horn proved distinctly superior to that of the gun. This *selective* power of the atmosphere revealed itself more strikingly in our autumn experiments than in our summer ones; and it was sometimes illustrated within a few hours of the same day: of two sounds A and B for example, A would have the greatest range at 10 A.M. and B the greatest range at 2 P.M.

* In all cases nautical miles are meant.

In the experiments on the 19th and 20th of May, the superiority of the trumpets over the whistles was decided; and indeed, with few exceptions, this superiority was maintained throughout the inquiry. But there were exceptions. On June 2, for example, the sound of the whistles rose in several instances to full equality with, and on rare occasions subsequently even surpassed, that of the horns. The sounds were varied from day to day. On the date last mentioned a single horn was sounded, two were sounded, and three were sounded together; but the utmost range of the loudest sound, even with the paddles stopped, did not exceed six miles. With the view of concentrating their power, the axes of the horns had been pointed in the same direction, and, unless stated to the contrary, this in all subsequent experiments was the case.

On the 3rd of June the three guns already referred to were permanently mounted at the South Foreland. They were well served by gunners from Dover Castle.

On June 3 dense clouds quite covered the firmament, some of them particularly black and threatening, but a marked advance was observed in the transmissive power of the air. At a distance of 6 miles the horn-sounds were not quite quenched by the paddle-noises; at 8 miles the whistles were heard, and the horns better heard; while at 9 miles, with the paddles stopped, the horn-sounds alone were fairly audible. During the day's observations a remarkable and instructive phenomenon was observed. Over us rapidly passed a torrential shower of rain, which, according to DERHAM, is a potent damper of sound. I could, however, notice no subsidence of intensity as the shower passed. It is even probable that, had my mind been free from bias, I should have noticed an augmentation of the sound, such as occurred with the greatest distinctness on various subsequent occasions during violent rain.

The influence of "beats" was tried on June 3, by throwing the horns slightly out of unison; but though the beats rendered the sound characteristic, they did not seem to augment the range. At a distance from the station curious fluctuations of intensity were noticed. Not only did the different blasts vary in strength, but sudden swellings and fallings off, even of the same blast, were observed. This was not due to any variation on the part of the instruments, but purely to the changes of the medium traversed by the sound. What these changes were shall be indicated subsequently.

During the inquiry various shiftings of the horns and reeds were resorted to, with a view of bringing out their maximum power. The range of our best horns on June 10 was $8\frac{3}{4}$ miles. The guns at this distance were very feeble. That the loudness of the sound depends on the shape of the gun was proved by the fact that thus far the howitzer, with a 3-lb. charge, proved more effective than the other guns. In the axis of the horns the sound manifests its greatest strength, falling sensibly off as the angular distance from the axis is augmented. Now the whistles have no such axes, but send their sound-waves with equal strength in all directions. Hence, as the horns pointed seaward, near the line joining the Foreland and the South Sand Head light-vessel on the one hand, and that joining the Foreland and the Admiralty Pier on the other, the whistles were sometimes more than a match for the horns.

§ 4. *Influence of Sound-Shadow.*

On the 19th of May we noticed a phenomenon of grave import in connexion with the establishment of fog-signals. I refer to the rapid fall of intensity on both sides of the signal-station at the South Foreland. We had halted between the station and the South Sand Head light-ship, at a distance of $2\frac{1}{2}$ miles from the former. The trumpets and whistles were sounded, but they were quite unheard. We moved nearer; but even at a mile distance, with the instruments plainly in view, their sound failed to reach us. A light wind, however, was here opposed to the sound. Abreast of the signal-station the trumpets were very powerful; but on approaching the line joining the Foreland to the end of the Admiralty Pier the sound fell rapidly, though in this case the wind was favourable to the sound. Plainly, therefore, some other cause than the wind must be invoked to account for the phenomenon.

On the 10th of June the same effect was very strikingly manifested. After our day's work we steamed past the Foreland and towards the end of the Pier. At the distance of a mile the sounds fell with such rapidity that I thought something must have occurred to the whistles and horns. Happily the guns were there to test this surmise. At 2 miles distance we signalled for them. With a 3-lb. charge, though their puffs were clearly seen, not one of them was heard; with a 6-lb. charge the 18-pounder was barely heard, the howitzer was slightly better heard, while the mortar was quite unheard. No peculiarities of the horns or whistles could therefore account for the phenomenon.

On the 11th of June the effect was equally pronounced. On the line joining the Foreland and the Admiralty Pier, and at $\frac{3}{4}$ of a mile from the station, the sound rapidly sank in power, and soon afterwards became inaudible. At $1\frac{1}{4}$ mile distance we signalled for the guns; the report in each case was a low indistinct thud. A necessary requirement in fog-signals is stated to be that they should, under all circumstances, be heard to a distance of 4 miles. Now the gun was undoubtedly the signal of greatest range when this inquiry began, and here we find that conditions may exist which render even the gun ineffectual at less than half the distance deemed essential.

The Map on Plate XIX., which consists of a portion of Plate XVII. enlarged, will help us to an explanation of these observations. Near the fog-signal station a projecting chalk cliff at C receives the impact of the sonorous waves and disperses them by reflection. The whole sea space between the line A B and the cliffs under Dover Castle is in the sound-shadow. Within this line the instruments cannot be seen, without it they can; and we have to account for the fact that the enfeeblement of the sound occurs not only inside but immediately outside the boundary, and while the instruments are in sight. A sudden subsidence of the sound is always observed on crossing the boundary towards the shore, and a correspondingly sudden augmentation on crossing it towards the sea; but the stoppage of the sound on entering the shadow is by no means total. The whole of the shaded space is filled with sound of enfeebled intensity, produced in great part by the divergence into the shadow of the waves which abut against the boundary. Through this divergence the direct waves suffer, the portions nearest to

the shadow suffering most. (On the Map the condensations and rarefactions of the direct waves are shown by circular lines of varying closeness.) Here, then, we have one cause of the decay of the sound in the neighbourhood of the acoustic shadow. Another cause is the interference of the direct waves with those reflected from C and from other portions of the cliff. The remarks here applied to the sound-shadow west of the Foreland are also applicable to that upon the other side.

On July 25th a gradual improvement in the transmissive power of the air was observed from morning to evening; but at the last the maximum range was only moderate. The fluctuations in the strength of the sound were remarkable, sometimes sinking to inaudibility and then rising to loudness. A similar effect, due to a similar cause, is often noticed with church-bells. The acoustic transparency of the air was still further augmented on the 26th: at a distance of $9\frac{1}{4}$ miles from the station the whistles and horns were plainly heard against a wind with a force of 4; while on the 25th, with a favouring wind, the maximum range was only $6\frac{1}{2}$ miles. Plainly, therefore, something else than the wind must be influential in determining the range of the sound.

§ 5. *Rotation of Horn.*

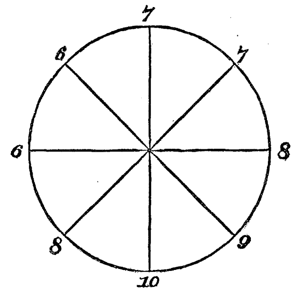
Thus far I have confined myself to the salient point or points of each day's observations, omitting numerous details. The observations of July 1 and 3 are, I think, of a character to bear a fuller treatment. Tuesday, July 1, was devoted to the further investigation of the sound-range, and also to obtaining additional information as to how the sound diminishes in intensity as we depart from the axis of the horn. It is obvious that for this purpose, instead of carrying the ship round the horn, we may cause the horn to rotate round its vertical axis while the ship maintains a fixed position.

On this occasion the steam-whistle from the United States was mounted, and sounded at different times during the day. The whistle is 12 inches in diameter, and it was blown at 70 lbs. pressure. The resonant bell of the whistle cannot be moved, a fixed distance existing between the circular ring from which the steam issues and the cutting-edge.

We steamed to a point on the axis which bore S.S.W. from the station. Wind calm on sea; on shore N.N.W., with a force of 3. We halted at a distance of $5\frac{1}{4}$ miles, and received a very good sound from the horn when it was pointed towards us. Forty-five degrees right and left of this, the sound was also good, but it became feebler as the departure from the axis was augmented.

To attempt applying numerical estimates to the sounds would be mere guesswork; still it will fix the ideas if I give a sample of the method by which the day's observations were conducted. A circle was drawn, the circumference of which was divided at eight points into equal parts, the radius drawn from the centre to those points representing the direction of the horn. Opposite to each point was placed a number indicative of the strength of the corresponding sound. Thus, assuming the intensity when the

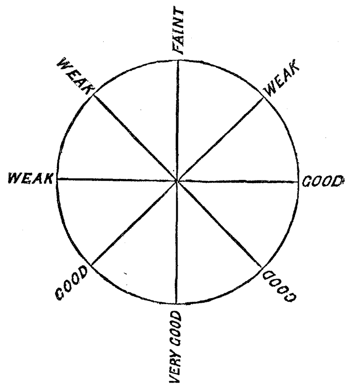
trumpet was pointed towards us to be represented by the number 10, the intensities when the trumpet was pointed in the other directions are represented by the other figures in the accompanying diagram*.



These are the actual numbers set down during a series of observations, but they are not to be taken as representing any thing further than the general decadence of the sounds as the trumpet was more and more turned away from us. Indeed there is every reason to believe that the decay is sometimes more rapid and considerable than is indicated by these numbers.

It may be remarked that a hoarding placed behind the trumpets contributed by reflection to augment the intensity of the sound when the trumpet was turned quite away from us.

In the annexed sketch the judgment of an observer is expressed in words instead of numbers. It may be stated that at different periods of the same day, the opinion of the same observer varied as to the relative intensities of the sounds in the several positions of the horn. The observation here recorded was made at a distance of $5\frac{1}{4}$ miles from the station.



For the better education of our ears we steamed closer to the Foreland, halting at $3\frac{3}{4}$ miles, and resting in this position during several rotations of the horn. The direct sound was very fine, the other sounds being expressed with approximate fairness by the numbers given in the first diagram. At $3\frac{6}{10}$ miles to windward (the wind, however, blowing only with a force of 2, and the water being smooth) the result was substantially the same. The day had become dark and lowering; the black and threatening clouds formed a kind of ceiling overhead, thereby possibly aiding the sound†, while haze was diffused between us and the station. For the purpose of making a signal, we steamed within 2 miles of the Foreland. On steaming out again the sounds were heard for some time through the paddle-noises; at about 4 miles distance they were lost, but they revived forcibly as soon as the paddles ceased moving; on resuming the motion they continued to be heard up to a distance of $6\frac{3}{4}$ miles.

At $7\frac{1}{2}$ miles the paddles were eased, and a strong sound was heard; at $9\frac{1}{2}$ miles the sound was good, but it appeared to be of lower pitch than at a less distance. The haze at this time quite hid the Foreland, a somewhat staggering result considering the acoustic clearness of the atmosphere. The wind S.W., force 2, appeared to be dead against the sound; but on shore it was N.W., with a force of 3, or nearly at right

* To Capt. Drew, I believe, we were indebted for this idea of a dial.

† This stands as it was written at the time; but I believe it is still to be proved that clouds, as such, have any sensible power of reflection.

angles to the direction of the sound. This variance in the records on shore and afloat is not uncommon at the Foreland, the formation of the land giving rise to local currents of air.

At a distance of 10 miles the horn once or twice yielded a plain sound, while the American whistle seemed to surpass the horn. We waited here for some time: at $10\frac{1}{2}$ miles occasional blasts of the horn came to us, but after a time all sound ceased to be audible; it seemed as if the air, after having been exceedingly transparent, had become gradually more opaque to the sound.

Returning along the same line, we halted and listened at a distance of $8\frac{1}{4}$ miles. The sounds were certainly much feebler than at 9 miles upon our journey out: it required attention and quiet on board to hear them at all. The haze continued, the cliffs of the Foreland being still hidden. At 6 miles we again halted: the sounds were indistinct, and not at all equal to those heard at $9\frac{1}{4}$ miles in coming out; they seemed, moreover, to have fallen in pitch: one of the observers described them as having degenerated to a kind of rumble. The sound as we approached the station became more and more unsatisfactory, and finally ceased. This we learned afterwards to be due to the breaking of the 2-inch reed of a wide horn. A narrower horn, which yielded a sound nearly equal to the large one, was used in the subsequent experiments.

At 4.45 P.M. we spoke the 'Triton,' and took the master of the Varne light-ship on board the 'Irené.' He and his company had heard the sound at intervals during the day, although he was dead to windward and distant $12\frac{3}{4}$ miles. All day long, however, the wind continued light, the force being only 2.

Here a word of reflection on our observations may be fitly introduced. It is, as already shown, an opinion entertained in high quarters that the waves of sound are reflected at the limiting surfaces of the minute particles which constitute haze and fog, the alleged waste of sound in fog being thus explained. If, however, this were an efficient practical cause of the stoppage of sound, and if clear calm air be, as alleged, the best vehicle, it would be impossible to understand how to-day, in a thick haze, the sound reached a distance of $12\frac{3}{4}$ miles, while on May 20, in a calm and hazeless atmosphere, the maximum range was only from 5 to 6 miles. Such facts foreshadow a revolution in our notions regarding the action of haze and fogs upon sound.

Steaming directly in towards the Foreland, at $4\frac{1}{2}$ miles, with the paddles going, the sounds were well heard; at $3\frac{3}{4}$ miles upon the same bearing the loudest sound was very full. We steamed towards Dover Pier end, and at $2\frac{3}{10}$ miles from the station, on the line between it and the pier, all sounds, as usual, fell considerably. At a distance of $1\frac{1}{2}$ mile on the same line the loudest sound emitted by the horn during its rotation was very feeble. Inasmuch as this extraordinary subsidence of the sound occurred when the horn was turned towards us, it cannot be referred to the deviation from the axis: as already explained (§ 4), it is in part due to the weakening of the direct waves by diffraction, and in part, doubtless, to interference.

Wishing to examine the condition of the sound at the other side of the Foreland, we

steamed abreast of it at a distance of $\frac{1}{2}$ a mile: the sound of the horn was here exceedingly powerful. At a distance of 3 miles from the station, and on the line between it and the South Sand Head light-ship, the sounds were stronger than at the other side; but we were here both nearer to the axis and further removed from the interfering influence of the shore. Close to the shore on both sides of the station the turning of the horn produced greater variations of the sound than in the open sea in front of the station: in one case, indeed, where the maximum sound was marked 10, the minimum was set down at 2.

An interval of 12 hours sufficed to change in a surprising degree the acoustic transparency of the air. On the 1st of July the sound had a range of nearly 13 miles; on the 2nd the range did not exceed 4 miles.

§ 6. *Contradictory Results.*

Thus far the investigation proceeded with hardly a gleam of a principle to connect the inconstant results. The distance reached by the sound on the 19th of May was $3\frac{1}{2}$ miles; on the 20th it was $5\frac{1}{2}$ miles; on the 2nd of June 6 miles; on the 3rd more than 9 miles; on the 10th it was also 9 miles; on the 25th it fell to $6\frac{1}{2}$ miles; on the 26th it rose again to more than $9\frac{1}{4}$ miles; on the 1st of July, as we have just seen, it reached $12\frac{3}{4}$, whereas on the 2nd the range shrunk to 4 miles. None of the meteorological agents observed could be singled out as the cause of these fluctuations. The wind exerts an acknowledged power over sound, but it could not account for these phenomena. On the 25th of June, for example, when the range was only $6\frac{1}{2}$ miles, the wind was favourable; on the 26th, when the range exceeded $9\frac{1}{4}$ miles, it was opposed to the sound. Nor could the varying optical clearness of the atmosphere be invoked as an explanation; for on July 1, when the range was $12\frac{3}{4}$ miles, a thick haze hid the white cliffs of the Foreland, while on many other days, when the acoustic range was not half so great, the atmosphere was optically clear. Up to July 3 all remained enigmatical; but on this date observations were made which seemed to me to displace surmise and perplexity by the clearer light of physical demonstration.

§ 7. *Aërial Reflection and its Causes; solution of contradictions.*

On July 3 we first steamed to a point 2·9 miles S.W. by W. of the signal-station. No sounds, not even the guns, were heard at this distance. At 2 miles they were equally inaudible. But this being the position in which the sounds, though strong in the axis, invariably subsided, we steamed to the exact bearing from which our observations had been made upon July 1. At 2.15 P.M., and at a distance of $3\frac{3}{4}$ miles from the station, with calm clear air and a smooth sea, the horns and whistle (American) were sounded, but they were inaudible. Surprised at this result, I signalled for the guns. They were all fired, but, though the smoke seemed at hand, no sound whatever reached us. On July 1, in this bearing, the observed range of both horns and guns was $10\frac{1}{2}$ miles, while on the bearing of the Varne light-vessel it was nearly 13 miles. We steamed in to 3 miles,

paused, and listened with all attention; but neither horn nor whistle was heard. The guns were again signalled for; five of them were fired in succession, but not one of them was heard. We steamed in on the same bearing to 2 miles, and had the guns fired point-blank at us. The howitzer and the mortar, with 3-lb. charges, yielded a feeble thud, while the 18-pounder was wholly unheard. Applying the law of inverse squares, it follows that, with air and sea, according to accepted notions, in a far worse condition, the sound at 2 miles distance on July 1 must have had more than forty times the intensity which it possessed at the same distance at 3 P.M. on the 3rd.

"Over smooth water," says Sir JOHN HERSCHEL, "sound is propagated with remarkable clearness and strength." Here was the condition; still with the Foreland so close to us, the sea so smooth, and the air so transparent, it was difficult to realize that the guns had been fired or the trumpets blown at all. Had the sound been converted by internal friction into heat? or had it been wasted in partial reflections at the limiting surfaces of non-homogeneous masses of air? Sulphur in homogeneous crystals is exceedingly transparent to radiant heat, whereas the ordinary brimstone of commerce is highly impervious to it—the reason being that the brimstone of commerce does not possess the molecular continuity of the crystal, but is a mere aggregate of minute grains not in perfect optical contact with each other. Where this is the case, a portion of the heat is always reflected on entering and on quitting a grain: hence when the grains are minute and numerous this reflection is so often repeated that the heat is entirely wasted before it can plunge to any depth into the substance. The same remark applies to snow, foam, clouds, and common salt, indeed to all transparent substances in powder; they are all impervious to light, not through the immediate absorption or extinction of the light, but through repeated internal reflection.

HUMBOLDT, in his observations at the Falls of the Orinoco, is known to have applied these principles to sound. He found the noise of the Falls far louder by night than by day, though in that region the night is far noisier than the day. The plain between him and the Falls consisted of spaces of grass and rock intermingled. In the heat of the day he found the temperature of the rock to be considerably higher than that of the grass. Over every heated rock, he concluded, rose a column of air rarefied by the heat; and he ascribed the deadening of the sound to the reflections which it endured at the limiting surfaces of the rarer and the denser air. This philosophical explanation, which admits of experimental illustration in the laboratory, made it generally known that a non-homogeneous atmosphere is unfavourable to the transmission of sound.

But what on July 3, not with the variously heated plain of Antures, but with a calm sea as a basis for the atmosphere, could so destroy its homogeneity as to enable it to quench in so short a distance so vast a body of sound? I here submit to the judgment of scientific men my own course of thought regarding this question. As I stood upon the deck of the 'Irené' pondering it, I became conscious of the exceeding power of the sun beating against my back and heating the objects near me. Beams of equal power were falling on the sea, and must have produced copious evaporation. That the vapour

generated should so rise and mingle with the air as to form an absolutely homogeneous medium I considered in the highest degree improbable. It would be sure, I thought, to rise in streams, breaking through the superincumbent air now at one point now at another, thus rendering the air *flocculent* with wreaths and striæ, charged in different degrees with the buoyant vapour. At the limiting surfaces of these spaces, though invisible, we should have the conditions necessary to the production of partial echoes and the consequent waste of sound.

Curiously enough, the conditions necessary for the testing of this explanation immediately set in. At 3.15 P.M. a solitary cloud threw itself athwart the sun, and shaded the entire space between us and the South Foreland. The production of vapour was suddenly checked by the interposition of this screen; hence the probability of suddenly improved transmission. To test this inference the steamer was immediately turned and urged back to our last position of inaudibility. The sounds, as I expected, were distinctly though faintly heard. This was at 3 miles distance. At $3\frac{3}{4}$ miles the guns were fired, both point-blank and elevated. The faintest pop was all that we heard; but we did hear a pop, whereas we had previously heard nothing, either here or three quarters of a mile nearer. We steamed out to $4\frac{1}{4}$ miles, where the sounds were for a moment faintly heard; but they fell away as we waited; and though the greatest quietness reigned on board, and though the sea was without a ripple, we could hear nothing. We could plainly see the steam-puffs which announced the beginning and the end of a series of trumpet-blasts, but the blasts themselves were quite inaudible.

It was now 4 P.M., and my intention at first was to halt at this distance, which was beyond the sound-range, but not far beyond it, and see whether the lowering of the sun would not restore the power of the atmosphere to transmit the sound. But after waiting a little, the anchoring of a boat was suggested, so as to liberate the steamer for other work; and though loth to lose the anticipated revival of the sounds myself, I agreed to this arrangement. Two men were placed in the boat and requested to give all attention so as to hear the sound if possible. With perfect stillness around them they heard nothing. They were then instructed to hoist a signal if they should hear the sounds, and to keep it hoisted as long as the sounds continued.

At 4.45 we quitted them and steamed towards the South Sand Head light-ship. Precisely 15 minutes after we had separated from them the flag was hoisted: the sound had at length succeeded in piercing the body of air between the boat and the shore.

We continued our journey to the light-ship, went on board, and heard the report of the lightsmen. Returning towards the Foreland, in answer to a signal expressing a wish to communicate with us, we manned a boat and pulled to the shore. The exhaustion of the ammunition was reported, but the horns and whistle continued to sound. We steamed out to our anchored boat, and then learned that when the flag was hoisted the horn-sounds were heard, that they were succeeded after a little time by the whistle-sounds, and that both increased in intensity as the evening advanced. On our arrival, of course we heard the sounds ourselves.

Thus far, therefore, the explanation given above entirely agrees with the results of observation; but we pushed the test further by steaming further out. At $5\frac{3}{4}$ miles we halted and heard the sounds: at 6 miles we heard them distinctly, but so feebly that we thought we had reached the limit of the sound-range; but while we waited the sounds rose in power. We steamed to the Varne buoy, which is $7\frac{3}{4}$ miles from the signal-station, and heard the sounds there better than at 6 miles distance. We continued our course outwards to 10 miles, halted there, but heard nothing.

Steaming, however, on to the Varne light-ship, which is situated at the other end of the Varne shoal, we hailed the master, and were informed by him that up to 5 P.M. nothing had been heard, but that at that hour the sounds began to be audible. He described one of them as "very gross, resembling the bellowing of a bull," which very accurately characterizes the sound of the large American steam-whistle. At the Varne light-ship, therefore, the sounds had been heard towards the close of the day, though it is $12\frac{3}{4}$ miles from the signal-station. I think it probable that, at a point 2 miles from the Foreland, the sound at 5 P.M. possessed fifty times the intensity which it possessed at 2 P.M. On our return to Dover Bay at 10 P.M., we heard the sounds, not only distinct but loud, where nothing could be heard in the morning.

In consequence of the position of the promontory very curious winds and currents establish themselves round the South Foreland. Mr. HOLMES was, as usual, at the Foreland on July 3; and he informed me that from the motion of the smoke of some passing steamers, and from the sails of sailing-vessels, he could recognize a curious circulation of the air. A slight wind would sometimes hug the shore to the N.E., then bend round and move towards the South Sand Head light-ship. And, in point of fact, the wind at the light-vessel had been S.W., with a force of 3, nearly the whole of the day; whereas with us it had passed from S.W. by W. to a dead calm, and afterwards to S.E. On shore also it had shifted from S.W. to S.E. The atmospheric conditions between the light-vessel and the Foreland were therefore different from those between us and the Foreland; and the consequence was that at the time when we were becalmed and heard nothing, the light-keepers at South Sand Head heard the sounds plainly.

§ 8. *Aërial Echoes.*

But both the argument and the phenomena have a complementary side, which we have now to consider. A stratum of air less than 3 miles thick on a calm day has been proved competent to stifle both the cannonade and the horn-sounds employed at the South Foreland; while, according to the foregoing explanation, this result was due to the irregular admixture of air and aqueous vapour, which filled the atmosphere with an impervious *acoustic cloud* on a day of perfect *optical* transparency. But, granting this, it is incredible that so great a body of sound could utterly disappear in so short a distance without rendering any account of itself. Supposing, then, instead of placing ourselves behind the acoustic cloud we were to place ourselves in front of it, might we not, in accordance with the law of conservation, expect to receive by reflection the sound which

had failed to reach us by transmission? The case would then be strictly analogous to the reflection of light from an ordinary cloud to an observer placed between it and the sun.

My first care in the early part of the day in question was to assure myself that our inability to hear the sound did not arise from any derangement of the instruments on shore. Accompanied by Mr. EDWARDS, who was good enough on this and some other days to act as my amanuensis, at 1 P.M. I was rowed to the shore, and landed at the base of the South Foreland Cliff. The body of air which had already shown such extraordinary power to intercept the sound, and which manifested this power still more impressively later in the day, was now in front of us. On it the sonorous waves impinged, and from it they were sent back to us with astonishing intensity. The instruments, hidden from view, were on the summit of a cliff 235 feet above us, the sea was smooth and clear of ships, the atmosphere was without a cloud, and there was no object in sight which could possibly produce the observed effect. From the perfectly transparent air the echoes came, at first with a strength apparently but little less than that of the direct sound, and then dying gradually and continuously away. A remark made by my talented companion in his note-book at the time shows how the phenomenon affected him:—"Beyond saying that the echoes seemed to come from the expanse of ocean, it did not appear possible to indicate any more definite point of reflection." Indeed no such point was to be seen; the echoes reached us, as if by magic, from absolutely invisible walls.

Here, in my opinion, we have the key to many of the mysteries and discrepancies of evidence which beset this question. The foregoing observations show that there is no need to doubt either the veracity or capability of the conflicting witnesses, for the variations of the atmosphere are more than sufficient to account for theirs. The mistake indeed hitherto has been, not in reporting incorrectly, but in neglecting the monotonous operation of repeating the observations during a sufficient time. I shall have occasion to remark subsequently on the mischief likely to arise from giving instructions to mariners founded on observations of this incomplete character.

The question of aërial echoes has an historic interest. While cloud-echoes have been accepted as demonstrated by observation, it has been hitherto assumed that audible echoes never occur in optically clear air. We owe this opinion to the admirable report of ARAGO on the experiments made to determine the velocity of sound at Montlhery and Villejuif in 1822*. ARAGO's account of the phenomenon observed by him and his

* Sir JOHN HERSCHEL gives the following account of ARAGO's observation:—"The rolling of thunder has been attributed to echoes among the clouds; and if it is considered that a cloud is a collection of particles of water, however minute, in a liquid state, and therefore each individually capable of reflecting sound, there is no reason why very loud sounds should not be reverberated confusedly (like bright lights) from a cloud. And that such is the case has been ascertained by direct observation on the sound of cannon. Messrs. ARAGO, MATTHIEU, and PRONY, in their experiments on the velocity of sound, observed that under a perfectly clear sky the explosions of their guns were always single and sharp; whereas when the sky was overcast, and even when a cloud came

colleagues is as follows:—"Avant de terminer cette note, nous ajouterons seulement que tous les coups tirés à Montlhery y étaient accompagnés d'un roulement semblable à celui du tonnerre, et qui durait de 20″ à 25″. Rien de pareil n'avait lieu à Villejuif; il nous est arrivé seulement d'entendre, à moins d'une seconde d'intervalle, deux coups distincts du canon de Montlhery. Dans *deux* autres circonstances le bruit de ce canon a été accompagné d'un roulement prolongé. Ces phénomènes n'ont jamais eu lieu qu'au moment d'apparition de quelques nuages; par un ciel complétement serein le bruit était unique et instantané. Ne serait-il pas permis de conclure de là qu'à Villejuif les coups multiples du canon de Montlhery résultaient d'échos formés dans les nuages, et de tirer de ce fait un argument favorable à l'explication qu'ont donnée quelques physiciens du roulement du tonnerre?"*

It is not here stated that at Montlhery the clouds were seen when the echoes were heard. The explanation of the Montlhery echoes is, if I understand right, an inference from observations made at Villejuif. The inference I think requires qualification. Some hundreds of cannon-shots have been fired at the South Foreland, many of them when the heavens were completely free from clouds, and never in a single case has a "*roulement*" similar to that noticed at Montlhery been absent. It follows, moreover, so hot upon the direct sound as to present hardly a sensible breach of continuity between the sound and the echo. This could not be the case if the clouds were its origin. A reflecting cloud, even at the short distance of 1000 yards, would leave a silent interval of 5 seconds between sound and echo; and had such an interval been observed at Montlhery, it could hardly have escaped record by the philosophers stationed there.

However this may be, the foregoing observations prove that air of perfect visual transparency is competent to produce echoes of great intensity and long duration. The subject is worthy of additional illustration. On the 8th of October, as already stated, the syren was established at the South Foreland. I visited the station on that day, and listened to the syren-echoes. They were far more powerful than those of the horn. Like the others they were perfectly continuous, and faded, as if into distance, gradually away. The direct sound seemed rendered complex and multitudinous by its echoes, which resembled a band of trumpeters first responding close at hand, and then retreating rapidly towards the coast of France. The syren-echoes had 11 seconds, those of the horn 8 seconds duration.

I moved away from the station so as to lower the power of the direct without at the same time weakening the reflected sound. This was done by dropping into the sound-shadow behind an adjacent eminence. The echoes thus heard were still more wonderful

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in sight over any considerable part of the horizon, they were frequently accompanied by a long continued roll like thunder."—*Essay on Sound*, par. 38.

Observations and experiments recorded further on show the conclusion that clouds, as such, have any sensible power at all of reflecting sound, to be problematical, if not erroneous.

* Connaiss. des Temps, 1825, p. 361.

than before. In the case of the syren, moreover, the reinforcement of the direct sound by its echo was distinct. About a second after the commencement of the syren-blast, the echo struck in as a new sound. This first echo, therefore, must have been flung back by a body of air not more than 600 or 700 feet in thickness. The few detached clouds visible at the time were many miles away, and could clearly have had nothing to do with the effect.

This mingling of the echoes with the direct sound was much more distinctly heard in the case of the syren than in the case of the horn. With the horn, indeed, the echo was first plainly heard after the direct sound had ceased.

As we descended towards St. Margaret's Bay, where the horn and syren were well shaded by the hill, it was difficult to say when the direct sound ceased and the echoes began, so near in point of sensible intensity were the echoes to the direct sound.

On the 10th of October I was again at the Foreland listening to the echoes, with results similar to those just described. On the 15th I had an opportunity of remarking something new concerning them. To the late Mr. DABOLL, of the United States, belongs the credit of bringing large trumpets into use as fog-signals. At Dungeness one of his horns had been erected under his own superintendence; and, wishing to make myself acquainted with its performance, we steamed thither on the 15th. The horn is worked by a caloric engine. Like the horns at the South Foreland it is vertically mounted, and like them bent near its extremity so as to present its mouth to the sea. It rotates automatically through an arc of 210°, halting at four different points on the arc and emitting a blast of 6 seconds duration, these blasts being separated from each other by intervals of silence of 20 seconds. The pressure in each case when the sound began was $8\frac{1}{2}$ lbs., and it sank during the blast to $5\frac{3}{4}$ lbs. per square inch.

I listened to the sound during several successive rotations of the horn: the augmentation was distinct when the axis of the horn was turned towards me. From the beach and from the lighthouse-tower I listened to the echoes: they were feeble compared with those of the syren, but were nevertheless very musical, and of 4 seconds duration. They were moreover purely aërial, as the heaven was quite free from clouds.

The 'Galatea' at first sent us a startling echo from her side. Being afterwards turned with her bow facing in, this echo almost entirely disappeared, leaving the continuous and gradually fading aërial echoes behind. Some ships were in sight, and when the horn accidentally pointed towards one of them, in the midst of the aërial echoes one would suddenly cease, thus breaking the uniform continuity of the sinking sound: the dying out would then continue. In the words of Admiral COLLINSON, who was at my side, the aërial sound, instead of ceasing suddenly and abruptly, "tapered away."

The new point observed was that as the horn rotated the echoes were always returned along the line in which the axis of the horn pointed. Standing either behind or in front of the lighthouse-tower, or closing the eyes so as to exclude all knowledge of the position of the horn, the direction of its axis when it sounded could always be inferred from the direction in which the aërial echoes reached the shore. Not only

therefore is knowledge of *direction* given by a sound, but it may also be given by the aërial echoes of the sound.

On various occasions, when the atmosphere was perfectly free from clouds, I have had myself rowed from the 'Galatea' to the Foreland Cliff to listen to the echoes. On the 16th of October, at half a mile from the shore, we stopped and found the syren-echoes at this distance very distinct. The sky being absolutely cloudless, the gig was manned, and we rowed in. As we approached the cliff, thus deepening the reflecting layer of air, the echoes augmented in intensity and duration. We did not quit the boat, but halted as near as possible to the water-mark. The echoes returned by the transparent and perfectly invisible atmosphere were of astonishing strength and sweetness.

On this day the whistles and syren were compared. The average duration of the syren-echoes was 11 seconds; that of the whistle-echoes 6 seconds. In all cases the sound with the longest echo had the greatest range.

With sounds of the same pitch the duration of the echoes might be taken as a measure of the penetrative power of the sound.

The earliest, strongest, and most trumpet-like tones are thrown back from the stratum of air less than a quarter of a mile in thickness, which is first pierced by the sound. After we had placed this air-stratum between us and the shore its echoes were withdrawn, the residual echoes being in consequence much feebler.

One additional illustration of this character will suffice. On the 17th of October, at about 5 P.M., the air being perfectly free from clouds, we rowed towards the base of the Foreland Cliff. The 'Galatea' being broadside on returned a loud echo to both syren and horns. It was a simple but wonderfully distinct copy of the original sound. At a certain moment it struck in, raised the intensity of the sound, then ceased, suddenly lowering the intensity, and leaving the long-drawn aërial echoes to pursue their course and die gradually into silence.

We landed, and passed over the seaweed to the base of the cliff. As I reached the base the position of the 'Galatea' was such that an echo of astonishing intensity was sent back from her side; it came as if from an independent source of sound established on board the steamer. As before, this echo ceased suddenly, leaving the aërial echoes to fade gradually away.

At the base of the cliff a series of concurrent observations gave the duration of the aërial syren-echoes from 13 to 14 seconds.

Lying on the shingle under a projecting roof of chalk, the somewhat enfeebled diffracted sound reached me, and I was able to hear with great distinctness, about a second after the starting of the syren-blast, the echoes striking in and reinforcing the direct sound. The first rush of echoed sound was very powerful, and it came, as usual, from a stratum of air 600 or 700 feet in thickness. On again testing the duration of the echoes, it was found to be from 14 to 15 seconds. The perfect clearness of the afternoon caused me to choose it for the examination of the echoes. It is worth remarking that this was our day of longest echoes, and it was also our day of greatest acoustic transparency,

this association suggesting that the duration of the echo is a measure of the atmospheric *depths* from which it comes. On no day, it is to be remembered, was the atmosphere free from invisible acoustic clouds; and on this day, and when their presence did not prevent the direct sound from reaching to a distance of 15 or 16 nautical miles, they were able to send us echoes of 15 seconds duration.

It remains to be added that on many occasions when the 'Galatea' was 2 miles and on some when she was 3 miles from the shore, with the Foreland bearing north, distinct and long-continued syren-echoes were sent back to us from the transparent *southern* air.

On various other occasions, when the atmosphere was exceptionally pure, we have fired the 'Galatea's' guns with a 1-lb. charge; echoes were always returned from that portion of the atmosphere towards which the gun was pointed.

Several times also during the prevalence of wind the ship has been turned across the wind and its two guns fired, the one to windward, the other to leeward. On all occasions the echoes of the leeward-pointed gun were distinctly more powerful and long-continued than those of the gun fired to windward.

To sum up this question of aërial echoes. The syren sounded three blasts a minute, each of 5 seconds duration. From the number of days and the number of hours per day during which the instrument was in action we can infer the number of blasts. They reached nearly twenty thousand. The blasts of the horns exceeded this number, while hundreds of shots were fired from the guns. Whatever might be the state of the weather, cloudy or serene, stormy or calm, the aërial echoes, though varying in strength and duration from day to day, were never absent; and on many days "under a perfectly clear sky" they reached, in the case of the syren, an astonishing intensity.

§ 9. *Experimental Demonstration of the stoppage of Sound by Aërial Reflection.*

The stoppage of sound by aërial reflection has never been experimentally demonstrated; it has been hitherto a matter of inference, and I wished to reduce it to experimental demonstration. A few preliminary experiments satisfied me that a carefully constructed apparatus would be necessary for the purpose. I therefore requested my assistant, Mr. COTTRELL, who is eminently skilful in devising apparatus the object of which has been made clear to him, to make an arrangement by which alternate layers of carbonic acid and coal-gas, the one falling by its weight, the other rising by its lightness, should be obtained. After making in the first instance a rough model himself, he invoked the aid of an intelligent carpenter, and produced the instrument represented in section and plan in figs. 1, 2, & 3, Plate XVIII.

X Y (fig. 1) is the sectional elevation of a wooden tunnel with a glass front. B is a small bell enclosed in a carefully padded box with one opening, worked sometimes by electricity and sometimes by a small magneto-electric engine. The letters *a*, *b*, *c*, *d*, *e*, &c. indicate the front view of a series of pewter tubes about $\frac{3}{4}$ of an inch wide, bent over at the top, and inserted into a box behind X Y. The box is seen in plan at *r s*, fig. 2. Into it is inserted the tube *m n*, with an orifice and trunk-tube at *o*, this trunk-tube

being connected with an india-rubber bag filled with carbonic-acid gas. The apparatus looked at "end on" is shown in fig. 3. Here also is shown the section of a second box, r', in all respects similar to the first, furnished like the first with a tube behind, and connected by a trunk-tube with the gas-main of the Institution. The course pursued by the two gases when the cocks are turned on will be evident on inspecting fig. 3. The carbonic acid, entering from its box into the tunnel X Y, falls in layers across the tunnel, and escapes by a series of apertures placed vertically under its places of entrance; the lower arrows in fig. 1 mark the course of the carbonic acid. The coal-gas, on the other hand, entering from its box below rises in layers between the carbonic-acid layers, and escapes through a series of apertures at the top of the tunnel. The upper arrows in fig. 1 mark the course of the coal-gas. In this way five-and-twenty layers of the heavier gas, separated from each other by layers of the lighter one, are obtained, the limiting surfaces at which reflection takes place being therefore fifty in number.

With the ear properly defended and applied to the end of the tunnel, this apparatus proves effective; but an excellent objective test is furnished by one of the sensitive flames discovered by LECOMTE, observed some years subsequently by BARRETT, and described, with variations and extensions, in my sixth Lecture on Sound. Such a flame is represented at fig. 1 issuing from the burner S. It is protected from air-currents by a glass bulb surrounding its lower portion, and through the bulb passes the shank of a funnel intended to concentrate the sound.

The tube t leading to the sensitive flame being connected with a gas-holder, the bell B is set ringing, and the pressure on the gas is exalted until the flame F, acted upon by the sonorous waves from the bell, trembles violently and roars. A few preliminary trials instruct us as to the necessary pressure. The two gases are now turned on, and after a few seconds the light and heavy layers establish themselves within the tunnel; the sound is stopped, the roaring trembling flame becomes immediately tranquil and burns steadily at a multiple of its height when agitated. The stoppage of the sound by aërial reflections is thus demonstrated. When the tunnel is explored with the beam of the electric lamp, it is found perfectly clear optically. The cause which so powerfully affects the sound does not sensibly affect the light; and it will be shown subsequently that agents which powerfully affect light have no sensible influence upon sound. By cutting off the two gases their places are immediately taken by air, the homogeneity of the medium is restored, and the flame is again shortened to a fraction of its normal height and thrown into violent agitation. The experiment can be repeated at pleasure, with the same unfailing result.

Not only do gases of different densities act thus upon sound, but atmospheric air saturated in different degrees with the vapours of volatile liquids can be shown by experiment to produce the same effect. Introducing, for example, into the path pursued by the coal-gas in the last experiment one of the flasks which I have so frequently employed to charge air with vapour*, partially filling the flask with a volatile liquid,

* Philosophical Transactions, 1870, vol. clx. p. 337.

and permitting air to bubble through the liquid and enter the tunnel X Y, we divide the tunnel into spaces of air saturated with the vapour, and spaces of air in its ordinary condition. The action of such a medium upon the sound-waves issuing from the bell B is very energetic, instantly reducing the violently agitated flame to stillness and steadiness as long as it continues to be the vehicle of the sound. The removal of the heterogeneous medium instantly restores the noisy flaring of the flame.

That differences of density due to differences of temperature produce partial echoes and waste of sound is also capable of experimental demonstration. Across a tunnel resembling X Y sixty-six platinum wires were stretched, all of them being in metallic connexion. The bell B, in its padded box, was placed at one end of the tunnel, and the sensitive flame F, near its flaring-point, at the other. When the bell rang the flame flared. A current from 50 cells being sent through the platinum wires, layers of warm air rose from them through the tunnel, and immediately the agitation of the flame was stilled: on stopping the current the agitation recommenced. In this experiment the platinum wires were not heated to redness. Employing half the number and the same battery, they were raised to a red heat, the action in this case upon the sound-waves being also energetic. Employing one third of the number, with the 50 cells, the wires were raised to a white heat; and here also the flame was immediately rendered tranquil by the stoppage of the sound. A number of experiments executed by Mr. COTTRELL at my request showed that 66 wires at a dark heat act a little more strongly upon the sound-waves than 33 at a red heat or than 22 at a white heat*.

A few details of the experiments on the action of non-homogeneous atmospheres produced by the saturation of layers of air with the vapours of volatile liquids may follow here.

To secure a more uniform distribution of the layers of vapour in the tunnel X Y, the box *r s* (fig. 2, Plate XVIII.) was subsequently divided into three compartments, because, with the arrangement described in § 9, the air at the centre of the tunnel remained homogeneous after its two ends had become heterogeneous. In all cases the saturated air was forced in layers upwards, while common air was forced downwards; with the vapours of the liquids here mentioned the following results were obtained:—

Bisulphide of carbon.—Flame very sensitive; the action of the non-homogeneous atmosphere prompt and strong.

Chloroform.—Flame still very sensitive; action similar to the last.

Iodide of ethyl.—Action decided, but weak.

Iodide of methyl.—Action prompt and energetic.

Benzol.—Action decided, but very weak.

Amylene.—Very fine action, prompt and energetic. Rendered a short and violently agitated flame tall and quiescent.

Sulphuric ether.—Action prompt and energetic.

* Mr. COTTRELL himself has shown, in a very striking manner, the reflection of sound from a single layer of heated air (Proc. Roy. Soc. vol. xxii. p. 190). The action of a hot poker is also quite distinct.

Formic ether.—Action decided, but weak.

Alcohol.—No sensible action. A more delicate test is necessary *.

Acetic ether.—Action decided, but weak.

Nitrite of amyl.—Action uncertain.

Toluol.—No sensible action.

Valerianic ether.—No sensible action.

Butyric ether.—No sensible action.

Acetone.—Action very weak.

When the flasks containing iodide of ethyl, formic ether, and acetone were placed in warm water, their vapours exerted a strong action. The warming of valerianic ether, butyric ether, and alcohol, on the contrary, produced no sensible effect.

In all cases where an action was observable, the air-bags used to force air downwards might be suppressed, the saturated air only being forced across the tunnel; the result was the same as when common air was forced from bags in a direction opposed to that of the saturated air.

The action of non-homogeneous atmospheres is well shown by placing a ticking watch at 6 inches from the ear. The heated air-column from a Bunsen's rose-burner utterly stops the sound. I may add that all these results may be obtained with an apparatus only a fraction of the length of that first employed, and figured on Plate XVIII.

§ 10. *Action of Hail and Rain.*

The explanation here given is in harmony with other facts, while these facts are irreconcilable with prevalent notions. DERHAM, and after him all other writers, considered that falling rain tended powerfully to obstruct sound. I have already referred to an observation on June 3 which tended to throw doubt on this conclusion. Two other crucial instances will suffice to show its untenability. On the morning of October 8, at 7.45 A.M., a thunderstorm accompanied by heavy rain broke over Dover. But the clouds subsequently cleared away and the sun shone strongly on the sea. For a time the optical clearness of the atmosphere was extraordinary, the coast of France, the Grisnez lighthouse, and the Monument and Cathedral of Boulogne being clearly visible in positions from which they were generally quite hidden. The atmosphere at the same time was acoustically opaque. At 2.30 P.M. a densely black scowl again overspread the heavens to the W.S.W. At this hour, the distance being 6 miles, the horn was heard very feebly, the syren more distinctly. The howitzer was better than either, though not much superior to the syren. All was hushed on board during these observations.

A squall now approached us from the west. In the Alps or elsewhere I have rarely seen the heavens blacker. Vast cumuli floated in the N.E. and S.E.; vast streamers of rain were seen descending W.N.W.; huge scrolls of cloud to the N.; but spaces of blue were to be seen to the N.N.E.

* While this paper was passing through the press the action both of aqueous vapour and of the vapour of alcohol mixed with air upon sound was experimentally demonstrated.

At 7 miles distance the syren was not strong and the horn was very feeble.

At 3 P.M. the gun was fired, and it sent to us a very faint report, hardly equal to the sound of the syren. A dense shower now enveloped the Foreland.

The rain at length reached us; but although it was falling heavily all the way between us and the Foreland the sound, instead of being deadened, rose perceptibly in power. Hail was now added to the rain, and the shower reached a tropical violence. The deck was thickly covered with hailstones, which here and there floated upon the rain-water, the latter not having time to escape. We stopped. In the midst of this furious squall both the horns and the syren were distinctly heard; and as the shower lightened, thus lessening the local pattering, the sounds so rose in power that we heard them at a distance of $7\frac{1}{2}$ miles distinctly louder than they had been heard through the rainless atmosphere at 5 miles. This observation is entirely opposed to prevalent notions, but it harmonizes perfectly with the explanation of our experience on the 3rd of July, according to which water in the state of *vapour*, and so mixed with air as to form non-homogeneous parcels, acts powerfully in wasting sound. Under the action of a strong sun, prior to the rain, the air had been in this flocculent condition, but the descent of the shower restored in part the homogeneity of the atmosphere and augmented its transmissive power.

At 4 P.M. the rain had ceased and the sun shone clearly out: the air was calm afloat, but W., with a force of 2, ashore. At 9 miles distance the horn was heard feebly, the syren clearly, while the howitzer sent us a loud report. All the sounds were better at this distance than they had previously been at $5\frac{1}{2}$ miles; from which it follows that the intensity of the sound at $5\frac{1}{2}$ miles must have been augmented at least threefold by the descent of the rain.

The other instance to which I have to refer occurred on the 23rd of October. Our steamer had forsaken us for shelter, and I sought to turn the weather to account by making observations on the influence of the wind. Mr. DOUGLASS, the chief Engineer of the Trinity House, was good enough to undertake the observations N.E. of the Foreland; while Mr. AYRES, the Assistant Engineer, walked in the other direction. At 12.50 P.M. the wind blew a gale and broke into a thunderstorm with violent rain. Inside and outside the Cornhill Coastguard Station Mr. AYRES heard the sound of the syren distinctly through the storm, and after the rain had ceased all sounds were heard distinctly louder than before. Mr. DOUGLASS had sent a fly before him to Kingsdown; and the driver had been waiting for fifteen minutes before he arrived. During this time no sound had been heard, though 40 blasts had been blown; nor had the coastguard man on duty, who had been accustomed to observe the sounds, heard any of them throughout the day. During the thunderstorm, and while the rain was actually falling with a violence which Mr. DOUGLASS assures me was more like the descent of a water-spout than of ordinary rain, the sounds became audible and were heard by all. Prior to the thunder-storm the atmosphere, according to my explanation, was rendered acoustically flocculent by wreaths and streaks of mixed air and vapour. Through the precipitation of the

vapour during the storm the heterogeneity thus arising was in great part abolished, and a freer passage opened for the sound through the atmosphere.

To rain, finally, I have never been able to trace the slightest deadening influence upon sound. The reputed barrier offered by "thick weather" to the passage of sound was one of the causes which tended to produce hesitation in establishing sound-signals on our coasts. It is to be hoped that the removal of this error may redound to the advantage of coming generations of seafaring men.

§ 11. *Action of Snow.*

Falling snow, according to DERHAM, offers a more serious obstacle than any other meteorological agent to the transmission of sound. We have not extended our observations at the South Foreland into snowy weather; but I may be permitted to refer to an observation of my own which bears directly upon this point. On Christmas night, 1859, I arrived at Chamouni, through snow so deep as to obliterate the road-fences, and to render the labour of reaching the hamlet arduous in the extreme. On the 26th and 27th it fell heavily. On the 27th, during a lull in the storm, I reached the Montanvert, sometimes breast-deep in snow. On the 29th the entry in my journal is, "Snow, heavy snow; it must have descended through the entire night, the quantity freshly fallen is so great." Dr. DERHAM had referred to the deadening effect produced by a coating of fresh fallen snow upon the ground, alleging that when the surface was glazed by freezing the damping of the sound disappeared.

On December 29 I took up a position beside the Mer de Glace, with a view to determine its winter motion, and sent my assistants across the glacier with instructions to measure the displacement of a transverse line of stakes planted previously in the snow. I was standing at the time beside my theodolite, having waded to the position through snow which, being dry, reached nearly to my breast. A storm drifted up the valley, darkening the air as it approached. It reached us, the snow falling more heavily than ever I had seen it elsewhere. It soon formed a heap on the theodolite; still through the telescope I was able to pick up at intervals the retreating forms of the men. Here there was a combination of thick snow in the air, and of soft fresh snow on the ground such as DERHAM could hardly have enjoyed. Through such an atmosphere, however, I was able with my unaided voice to make my instructions audible for half a mile, while the experiment was rendered reciprocal by one of my assistants* making his voice audible to me.

Many years ago I mentioned this fact in the presence of Sir JOHN HERSCHEL, and I have a distinct recollection of the surprise with which he heard it. And, indeed, in relation to our previous convictions, it is simply astonishing to observe the facility with which sound makes its way among obstacles, and even penetrates solid bodies, so long as the continuity of the air in their interstices is preserved. The following experiments illustrate this.

* Mr. JOSEPH TAIRRAZ, now a photographer at Chamouni.

A piece of millboard or of glass, a plank of wood, or the hand placed across the open end Y of the tunnel X Y (Plate XVIII.) intercepts the sound of the bell B and stills the sensitive flame F.

An ordinary cambric pocket-handkerchief stretched across the tunnel end produced hardly an appreciable effect upon the sound, the flame being sensibly as much agitated when it was present as when it was absent. Sending the sound through two layers of the handkerchief, the flame continued to be much agitated; through four layers the flame was still agitated, while through six layers the flame, though nearly stilled, was not entirely so.

Dipping the same handkerchief in water, and stretching a single wetted layer across the tunnel, it stilled the flame as effectually as the millboard or the plank of wood. It is obvious therefore that the sound-waves in the first instance had passed through the interstices of the cambric.

Through a single layer of a thin silk handkerchief the sound passed without sensible interruption; through six layers of the same handkerchief the flame was strongly agitated; while through twelve layers the agitation was quite perceptible. Looking at the sun, a feeble luminosity was perceived through six layers of the silk, while twelve layers totally intercepted the light. It would be easy to multiply instances such as this of bodies opaque to light and transparent to sound.

A single layer of this silk, when wetted, stilled the flame.

A layer of soft lint produced but little effect upon the sound; a layer of thick flannel was almost equally ineffectual. Through four layers of the flannel the flame was perceptibly agitated by the sound. Through a single layer of green baize the sound passed almost as freely as through air; through four layers of the baize the action was still sensible. Through a layer of close hard felt, half an inch thick, the sound-waves passed with sufficient energy to sensibly agitate the flame.

Oiled silk has no sensible interstices; a single thin layer of this substance stopped the sound and stilled the flame. A single layer of goldbeater's skin did the same. A leaf of common note-paper, or even of foreign post, stopped the sound. A single column of heated air rising from a Bunsen's flame in front of the tunnel has been proved by Mr. COTTRELL sufficient to still the sensitive flame.

The sensitive flame is not absolutely necessary for these experiments. Let a ticking watch be hung 6 inches from the ear, a cambric handkerchief dropt between it and the ear scarcely sensibly affects the ticking, a sheet of oil-skin or a heated gas column cuts it almost wholly off.

But though oiled silk, foreign post, and even goldbeater's skin can stop the sound, when the film becomes sufficiently thin to yield freely to the aërial pulses the sound is transmitted through the film. A thick soap-film produces a sensible effect upon the flame, a very thin one does not. The augmentation of the transmitted sound may be observed simultaneously with the generation and brightening of the colours of the film. A thin collodion-film acts in the same way.

Acquainted with the foregoing facts regarding the passage of sound through cambric, flannel, baize, and felt, the reader will be prepared for the statement that the sound-waves pass without sensible impediments through heavy artificial showers of rain, hail, and snow.

§ 12. *Action of Fog. Observations in London.*

But the mariner's greatest enemy, fog, is still to be dealt with; and here for a long time the proper conditions of experiment were absent. Up to the end of November we had had frequent days of haze, sufficiently thick to obscure the white cliffs of the Foreland, but no real fog. Still those days furnished demonstrative evidence that the notions entertained regarding the reflection of sound by suspended particles were wrong. On many days of the thickest haze the sound had twice the range that it attained in other days of perfect optical transparency. Such instances dissolved the association hitherto assumed between acoustic and optic transparency, but they left the action of dense fogs undetermined.

I conferred with the Elder Brethren as to the possibility of transferring the instruments to some portion of the coast more favoured by fogs than the South Foreland; but after due consideration the probability of spring fogs seemed so great, that it was decided to leave the instruments undisturbed and to await the expected appearance of the fog. Other duties called me to London, where on December 9th a memorable fog set in. I telegraphed to the Trinity House, suggesting some gun observations. A prompt reply informed me that such observations would be made in the afternoon at Blackwall or in its neighbourhood. I went to Greenwich in the hope of hearing the guns across the river; but, owing to the delay caused by the fog, the firing had ended before I arrived. Over the river the fog was very dense, and through it came various sounds with great distinctness. The signal-bell of an unseen barge rang clearly out at intervals, and I could hear the hammering at Cubittstown, on the opposite side of the river. So distinct were the strokes that they appeared close at hand, though the works were upwards of half a mile away; no deadening of the sound by the fog was apparent.

Captain Atkins, assisted by Mr. Edwards, took charge of the gun-observations. Up to a distance of 2 miles the report was good; at $2\frac{1}{4}$ miles, with much land intervening, the report was still heard. The firing was from a 12-pounder carronade with a charge of 1 lb. of powder; and this was heard through a dense fog distinctly better than the 18-pounder with a 3-lb. charge, and an optically clear atmosphere, on the 3rd of July.

The fog continuing unabated, on December 10 I sought to make some experiments upon a small scale over the Serpentine. I chose three organ-pipes of different lengths, a dog-whistle, a small bell struck by mechanism, and some percussion-caps. These were well heard across the Serpentine near the Watermen's Boathouse. At the same time I could converse with ease with my assistant across the water. The bell, the percussion-caps, and the shortest organ-pipe proving least effective, in subsequent experiments they were discarded in favour of the others.

In reply to my questions I was informed by two very intelligent policemen that they had

heard the bell of Westminster with great distinctness to-day, but that it had been heard still more loudly last night through exceedingly dense fog. On many clear days, they informed me, they fail to hear it at all. To-day the clangour at 12 o'clock was very loud.

At 3 P.M. I went again to the Serpentine; stationed my assistant, Mr. COTTRELL, with a whistle and organ-pipe on the walk below the south-west end of the bridge dividing Hyde Park from Kensington Gardens, while I went to the eastern end of the Serpentine. There I heard distinctly both the whistle and the pipe sounding Mi_3, which corresponds to 380 waves a second. The whistle was best heard. I then changed places with my assistant, and listening attentively at the bridge heard for a time the distinct blast of the whistle only. The organ-pipe at length sent its deeper note to me across the water; it sometimes rose to great distinctness, and sometimes fell to inaudibility. The whistle showed the same intermittence as to period, but in the opposite sense; for when the whistle was faint the pipe was strong, and *vice versâ*. To obtain the fundamental note of the pipe it had to be blown gently, and on the whole the whistle-sound proved itself the most efficient in piercing the fog.

There seemed to me to be an extraordinary amount of sound in the air on Dec. 10; it was filled with a resonant roar from the Bayswater and Knightsbridge roads. The railway-whistles, which were frequently blown, were extremely distinct, while the fog-signals exploded at the various metropolitan stations kept up a loud and almost constant cannonade. I could by no means reconcile this state of things with the statements so categorically made regarding the influence of fog on the sound of carriage-wheels and guns.

The Serpentine presented the instructive appearance to which I have already referred. The water was warmer than the air, and the ascending vapour was instantly in great part condensed, thus revealing its distribution. Instead of being uniformly diffused, it formed wreaths and striæ. I am pretty confident that had the vapour been able to maintain itself as such, the air to-day would have been more opaque to sound. In other words, I believe that the very cause which diminished the optical transparency of the atmosphere augmented its acoustic transparency.

On the 11th of December, the fog being denser than before, at 2.50 I stationed Mr. COTTRELL near the bridge, and took up a position myself near the end of the Serpentine. The whistle and the Mi_3 pipe were sounded in succession. I heard every blast of the whistle, and occasional blasts of the pipe. We reversed our positions, and I heard substantially the same, perhaps a little fainter. On joining my assistant at the bridge I heard the loud concussion of a gun, and was informed by a police-inspector that it came from Woolwich, and that he had heard several shots about 2 P.M. and previously. The fact, if a fact, was of the highest importance in relation to the present question; so I immediately telegraphed to my friend Professor ABEL, asking him for information. He was absent in Portsmouth when the telegram arrived, but on his return he found that guns had been fired at the proof-butts about the time mentioned in my telegram. On the following day he kindly furnished me with the following particulars:—

"The firing took place at 1.40 P.M. The guns proved were of comparatively small size—64-pounders, with 10-lb. charges of powder.

"The concussion experienced at my house and office, about three quarters of a mile from the butt, was decidedly more severe than that experienced when the heaviest guns are proved with charges of 110 to 120 lbs. of powder. There was a dense fog here at the time of firing."

These were the guns heard by the inspector; but on subsequent inquiry it was ascertained that two guns were fired at about 3 P.M. These were the guns heard by myself.

Professor ABEL also communicated to me the following fact:—"Our workmen's bell at the Arsenal Gates, which is of moderate size and any thing but clear in tone, is pretty distinctly heard by Professor BLOXAM *only* when the wind is *north-east*. During the whole of last week the bell was heard with great distinctness, the wind being *south-westerly*. The distance of the bell from BLOXAM'S house is about three quarters of a mile as the crow flies."

Slowly but surely we thus master this question; and the further we advance the more we are assured that our reputed knowledge regarding it has been erroneous from beginning to end. Fogs have no such power to deaden sound as, since the time of DERHAM, has been universally ascribed to them.

The vane on St. George's Chapel, Albemarle Street, pointed west during these observations, but, judged by sensation, the air was dead calm. On the night of the 11th the vane veered, and on the morning of the 12th it pointed N.E. The fog now attained its maximum density. I was unable to read at my window, which fronted the open western sky. At 10.30 I sent an assistant to the bridge, and listened for his whistle and pipe at the eastern end of the Serpentine. The whistle rose to a shrillness far surpassing any thing that I had previously heard, but it sank sometimes almost to inaudibility. At these special times of subsidence the organ-pipe came out distinctly. Acoustic clouds were drifting through the fog, and exercising a selective action on the sound. A second pipe, which was quite inaudible yesterday, was heard this morning. The fog was very dense.

I exchanged places with my assistant and heard both the whistle and the pipe in my new position; they were generally on the verge of inaudibility, and the pipe was only occasionally heard. Sometimes, however, both of them rose to great distinctness. The rise and fall of the sound resembled the intermittent augmentation and diminution of light by the passage of clouds of varying density across the sun. We were able to discourse across the Serpentine to-day with much greater ease than yesterday.

On various occasions during our observations I had been able to fix the position of the Foreland in thick haze, and even in the acoustic shadow, by the direction of the sound. To-day I gave directions to Mr. COTTRELL to come up to the Watermen's Boathouse and sound his whistle as he came. He was entirely hidden by the fog; and I walked along the opposite side of the Serpentine, clearly appreciating for a time that the line joining us was oblique to the axis of the river. At length I came to a point

which I supposed to be exactly abreast of him, marked it, and on the following day, when the fog had cleared away, found that I was perfectly exact. If undisturbed by echoes, the ear, with a little practice, becomes capable of fixing with great sharpness the direction of a sound.

On reaching the Serpentine this morning the clangour of a peal of bells, which then began to ring, seemed so close at hand that it required some reflection to convince me that they were ringing to the north of Hyde Park. The sounds fluctuated wonderfully in power, sometimes pouring forth a wealth of sound and then sinking to sudden penury. They disclosed to the mind's eye the condition of the atmosphere through which these varying sounds were transmitted. Prior to the striking of eleven by the great bell of Westminster, a nearer bell struck with loud clangour. The first five strokes of the Westminster bell were afterwards heard, one of them being extremely loud; the six last strokes were inaudible. I subsequently stationed my second assistant to attend to the 12-o'clock bells. The clock which had struck so loudly at 11 was unheard at 12, while of the Westminster bell eight strokes out of twelve rendered themselves audible. To such astonishing changes is the atmosphere liable.

Wishing to test still further the acoustic fluctuations of the day, I sent Mr. COTTRELL and a younger assistant at 7 P.M. to the Serpentine. The Westminster bell striking seven was not at all heard, while the nearer bell already alluded to was heard distinctly. The fog had now cleared away, and the lamps on the bridge could be seen from the eastern end of the Serpentine burning brightly; but instead of the sound sharing the improvement of the light, what might be properly called an acoustic fog took the place of its predecessor. The whistle and organ-pipe were sounded, three blasts of each in succession, several times; one series only of the whistle was heard, all the other blasts being quite inaudible. Three series of the organ-pipe were heard, but exceedingly faintly. On reversing their positions and sounding as before, nothing whatever was heard.

At 8 o'clock the chimes and hour-bell of the Westminster clock were very loud. The "acoustic fog" had shifted its position or temporarily melted away.

An assistant placed at the end of the Serpentine sounded the whistle and pipe for fifteen minutes without interruption. An observer at the bridge noticed the fluctuations of the sound. Sometimes the whistle was heard alone, sometimes the organ-pipe. Sometimes both whistle and pipe began strongly and ended by sinking almost to inaudibility. Extraordinary fluctuations were also observed in the case of the bells to which reference has been already made: in a few seconds they would sink from a loudly ringing peal into utter silence, from which they would rapidly return to loud-tongued audibility. The intermittent drifting of fog over the sun's disk (by which his light is at times obscured, at times revealed) is, as already stated, the optical analogue of these acoustical effects. In fact, as regards such changes, the acoustic deportment of the atmosphere is a true transcript of its optical deportment.

At 9 P.M. three strokes only of the Westminster clock were heard; the others were inaudible. The air had in part relapsed into its condition at 7 P.M., when all the strokes

were unheard. The quiet of the park this evening, as contrasted with the resonant roar which filled the air on the two preceding days, was very remarkable. The sound, in fact, was stifled in the optically clear but acoustically more flocculent atmosphere.

On the 13th, the fog being displaced by a thin haze, I went with my assistants again to the Serpentine. We could plainly see from one bank to the other, and far into Hyde Park beyond. When I rose this morning the vane pointed S.E., but before starting it had moved on to N.W., and on our return it pointed W. The motion of the air, however, was of the lightest kind, at no time reaching a force of 1. The carriage-sounds were damped to an extraordinary degree. The roar of the Knightsbridge and Bayswater roads had subsided, the tread of troops which passed us a little way off was unheard, while at 11 A.M. both the chimes and the hour-bell of the Westminster clock were stifled. The air had become milder; the hoar-frost had disappeared from the grass, though a residue still overspread the walks. At the end of the Serpentine I listened for the sounds from the bridge, and heard them. The pipe was in general the best, but all sounds were exceedingly faint, and the whistle was often inaudible. We reversed our positions, and I at the bridge listened for the sounds excited at the end of the Serpentine. With the utmost stretch of attention I could hear nothing.

This failure of hearing occurred upon a day when the local noises were far less disturbing than they had previously been. The sounds of the carriage-wheels were low and muffled, the bells were for the most part inaudible, and, with the exception of one far faint sound, the locomotive-whistles were unheard. Subjectively considered all was favourable to auditory impressions; but the very cause that damped the local noises extinguished our experimental sounds. The voice across the Serpentine to-day, with my assistant plainly visible in front of me, was distinctly feebler than it had been when each of us was hidden from the other in the densest fog.

I sought to obtain a numerical estimate of the decay of the sound, and with this view stationed Mr. COTTRELL at the eastern end of the Serpentine, while I walked along its edge from the bridge towards the end. The distance between these two points is about 1000 paces. After I had stepped 500 of them the sound was not so distinct as it had been at the bridge on the day of densest fog: hence the optical cleansing of the air by the melting of the fog had so darkened it acoustically, that a sound generated at the end of the Serpentine was lowered to at most one fourth of its intensity at a point midway between the end and the bridge.

I add two or three more of these domestic observations, and then pass to others made with actual fog-signals at the South Foreland. On several of the first days of this year I placed myself beside the railing of St. James's Park, near Buckingham Palace, three quarters of a mile from the clock-tower. Not a single stroke of "Big Ben" was heard at noon. These days were moist and warm, the air was calm, and the clock-tower in sight. On January 19 fog and drizzling rain obscured the tower; still from the same position I heard not only the strokes of the bell but also the preceding chimes of the quarter bells. The air was calm at the time.

During the exceedingly dense and "dripping" fog of January 22 I placed myself near the same railings and heard every stroke of the bell. On the same day an assistant at the end of the Serpentine, when the fog was densest, heard the Westminster bell striking loudly eleven. Towards evening this fog began to melt away, and at 6 o'clock I went to the end of the Serpentine to observe the effect of the optical clearing of the atmosphere upon the sound. Not one of the strokes reached me. At 9 o'clock and at 10 o'clock my able assistant Mr. COTTRELL was in the same position, and on both occasions failed to hear a single stroke of the bell. It was a case precisely similar to that of December 13, when the dissolution of the fog was accompanied by a decided acoustic thickening of the air.

On the morning of the 5th of February a dense fog filled London. At 10.45 I went to the Green Park and heard the chimes of the great bell in a position where on many clear calm days no sound had been audible. I walked thence to the eastern end of the Serpentine and heard the chimes at 11 A.M. Eight of the subsequent strokes of the bell reached me with marked power, the ninth and tenth (doubtless through the passage of an acoustic cloud) sank almost to inaudibility, while in the eleventh the sonorous power was restored. The air seemed dead calm at the time; no observable motion could be seen among the lightest twigs of the adjacent trees, but my breath was wafted in a direction opposed to the sound. Such observations show what instructive results may be obtained from a mode of observation accessible to all.

§ 13. *Experiments on Artificial Fogs.*

The smoke from smouldering brown paper was allowed to stream upwards into the tunnel X Y, Plate XVIII.; the action upon the sound-waves was strong, rendering the short and agitated sensitive flame F tall and quiescent.

Instead of the smoke and heated air, the heated air alone from four red-hot pokers was permitted to stream upwards into the tunnel; the action on the sound-waves was very decided, though the tunnel was optically empty.

A thick fog of chloride of ammonium was sent into the tunnel; a candle placed at one end could not be seen at the other, still there was no appreciable action upon the waves of sound.

Air first passed through ammonia, and then through hydrochloric acid, was sent into the tunnel; the agitated flame was rendered immediately quiescent, indicating a very decided action on the sound-waves. The flask containing the hydrochloric acid was, however, very warm, suggesting that differences of air-temperature might have come into play.

Air passed through perchloride of tin and sent into the tunnel produced exceedingly dense fumes. The action on the sound-waves was very strong.

The dense smoke of resin, burnt before the open end of the tunnel and blown into it with a pair of bellows, had the effect of stopping the sound-waves, so as to still the agitated flame.

Were these results due to the fumes or to differences of temperature? To the latter. The flame of a candle was placed at the tunnel end, and the hot air just above its tip was blown into the tunnel; the action on the sensitive flame was decided.

A red-hot iron was placed in the same position, and the heated air blown into the tunnel; the action on the sound-waves was decided.

In both these cases the tunnel remained optically clear, while the same effect as that produced by resin, gunpowder, and phosphorus was observed. To differences of temperature, therefore, and not to the fumes, the stoppage of the sound-waves in these cases was probably due.

To arrive at certainty on this head, instead of the tunnel a cupboard with glass sides, constructed some years ago for experiments on the floating matter of the air, was employed. It was 3 feet long, 2 feet wide, and about 5 feet high. In the closed cupboard it was thought fumes might be generated and permitted to remain until differences of temperature had sensibly disappeared. Two apertures were made in two opposite panes of glass 3 feet asunder; in front of one aperture was placed the bell, and behind the other, and at some distance from it, the sensitive flame.

The flame being brought into that condition that a very slight action on the sound-waves sufficed to reduce it from agitation to quiescence, phosphorus placed in a cup floating on water was burnt within the closed cupboard. The fumes were very dense. Considerably less than the 3 feet traversed by the sound sufficed to extinguish totally a bright candle-flame. At first there was a slight action upon the sound; but though the cloud remained of the same sensible density, the action rapidly vanished, and the flame was affected, as if the sound passed through pure air.

The cupboard was next filled with the dense fumes of gunpowder. At first there was a slight action; but this disappeared more rapidly than in the case of the phosphorus, the sound passing as if no fumes were there. It required less than half a minute to abolish the action in the case of the phosphorus, but a few seconds sufficed in the case of the gunpowder. The fumes were far more than sufficient to quench the candle-flame.

The smoke of resin, very dense and white, was next introduced. With a density far more than sufficient to quench the candle, the action on the sound-pulse was sensibly *nil.*

In this case the smoke was produced by bringing hot irons into contact with the resin. The same experiment was adopted with gum-mastic, the fumes of which produced no effect upon the sensitive flame.

The fumes of the perchloride of tin, though of extraordinary density, exerted no sensible effect upon the sound.

Exceedingly dense fumes of chloride of ammonium next filled the cupboard. A fraction of the length of the 3-foot tube sufficed to quench the candle-flame. Soon after the cupboard was filled the sound passed without the least sensible deterioration. An aperture at the top of the cupboard was opened; but though a dense smoke-column

ascended through it, many minutes elapsed before the candle-flame could be seen through the attenuated fog.

Steam from a copper boiler was so copiously admitted into the cupboard as to fill it with a dense cloud. No real cloud was ever so dense, still the sound passed through it without the least sensible diminution. This being the case, cloud-echoes, I think, are not a likely phenomenon.

In any and all of these cases, when a couple of Bunsen's burners were ignited within the cupboard containing the fumes, less than a minute's action rendered the air so heterogeneous that the sensitive flame was completely stilled.

The same occurred when the air within the cupboard was optically clear.

The foregoing experiments were repeated, the density of the fumes being tested by their action on the electric light. The density of these acoustically inactive fogs was such as to cut off the light totally, even when concentrated by a lens. The fumes themselves were illuminated by diffused light, but the carbon-points could not be seen.

The action of rain, hail, and snow was imitated by dense showers of water, sand, seeds, and bran: their action, within the limits employed, was *nil.*

§ 14. *Observations at the South Foreland.*

Satisfactory and, indeed, conclusive as these results were, I desired exceedingly to test in fog the instruments actually employed at the South Foreland. On the 10th of February it gave me great pleasure to receive the following note and enclosures from the Deputy Master of the Trinity House:—

"My dear Tyndall,—The enclosed will show how accurately your views have been verified, and I send them on at once without waiting for the details. I think you will be glad to have them, and as soon as I get the report it shall be sent to you. I made up my mind ten days ago that there would be a chance in the light foggy-disposed weather at home, and therefore sent the 'Argus' off at an hour's notice, and requested the Fog Committee to keep one member on board. On Friday I was so satisfied that the fog would occur that I sent Edwards down to record the observations. . . . .

"Very truly yours,

"Fred. Arrow."

The enclosures referred to were notes from Capt. Atkins and Mr. Edwards. Capt. Atkins writes thus to the Chairman of the Fog-Signal Committee:—

"As arranged I came down here by the mail express, meeting Mr. Edwards at Cannon Street. We put up at the 'Dover Castle,' and next morning at 7 I was awoke by the sounds of the syren. On jumping up I discovered that the long-looked-for fog had arrived, and that the 'Argus' had left her moorings.

"However, had I been on board, the instructions I left with Troughton [the Master of the 'Argus'] could not have been better carried out. About noon the fog cleared up and the 'Argus' returned to her moorings, when I learned that they had taken both syren- and horn-sounds to a distance of 11 miles from the station, where they dropt a

buoy. This I know to be correct, as I have this morning recovered the buoy, and the distances both in and out agree with TROUGHTON'S statement. I have also been to the Varne light-ship ($12\frac{3}{4}$ miles from the Foreland), and ascertained that during the fog of Saturday forenoon they 'distinctly' heard the sounds."

Mr. EDWARDS, who was constantly at my side during our summer and autumn observations, and who is thoroughly competent to form a comparative estimate of the strength of the sounds, informed the Deputy Master that the sounds were extraordinarily loud, both Capt. ATKINS and himself being awoke by them. He does not remember ever before hearing the sounds so loud in Dover; it seemed as though the observers were close to the instruments.

I here append Capt. ATKINS'S account of the observations made at the South Foreland during three days of fog culminating in the dense fog just referred to.

"Arrangements had been made for the 'Argus' remaining at Dover to wait for foggy weather, during which the instruments at the South Foreland might be tried.

"On Thursday, February 5, Mr. TROUGHTON, the master of the 'Argus,' reports that at 9 A.M. a dense fog-bank hung over the land, but that to seaward the atmosphere was clear. As the 'Argus' proceeded out to get on the S.S.W. line, the syren and horn were heard continually, the sounds being clear and distinct; but the noise of the paddles stifled the whistle-sound, which had been previously heard at Dover Pier while the vessel was still.

"At 9.52 reached the N.E. Varne buoy, $7\frac{3}{4}$ miles S.S.W. of the South Foreland and in the axis of the syren and horn. At this distance the syren- and horn-sounds were audible, although not strong; but as the tide carried the vessel towards the Varne light-ship the sounds diminished, and at $1\frac{1}{2}$ mile S.W. by W. of the buoy all sounds were lost. This was 9 miles from the station.

"Proceeded on to the Varne light-ship, $12\frac{3}{4}$ miles, the master of which vessel reports 'horns feeble in the N.E.' from 8.5 until 10.15 A.M. At 10.30 the 'Argus' proceeded N.E. by E., and at 3 miles from the light-ship (*i. e.* $9\frac{3}{4}$ miles from South Foreland) picked up the sounds of syren and horn with paddles going, and carried them into the Varne buoy, where at 11.8 the fog had cleared and the instruments ceased sounding.

"On this morning the fog was quite local and did not extend to sea; it hung about the land, but the sea horizon was clear and well defined.

"On Friday, February 6, Mr. TROUGHTON reports that at 8.25 A.M. there was a dense fog inshore, but that it was clear to seaward, although, as the morning advanced, there seemed to be drifting patches of fog and alternate spaces of thick and clear atmosphere. The sea was calm.

"At 8.25, by Dover Pier, the horn and syren were plainly heard, but the whistle was inaudible. At 9 A.M. proceeded from pier to N.E. Varne buoy, and carried the sound of the syren only out to the buoy; but the sound was not useful. Stopped at the buoy, $7\frac{3}{4}$ miles, and heard feeble but distinct sounds from both syren and horn, the whistle being inaudible. Drifted with tide half a mile S.W. of the buoy, and there lost all

sounds. Returned and recovered faint sounds at the buoy. Fog cleared at 10.15 and instruments ceased."

On Saturday morning, February 7, a very dense fog prevailed, apparently thicker at sea than on land; but on shore objects were invisible at between fifty and a hundred yards distance.

"At 8.15 A.M. the three sounds through the fog were astonishingly powerful, the syren particularly filling all the air with a loud and full sound. There was not the slightest difficulty in at once indicating the exact direction from which the sound proceeded.

"By 9 A.M. the atmosphere had begun to clear in the west, and as the day advanced the fog rolled slowly eastward. At 10 A.M. the line of demarcation between fog and clear atmosphere was a little to the eastward of the pier; and there was a marked difference between the sounds at this period and those of the early morning, a very sensible diminution in power being noticeable.

"Mr. TROUGHTON'S report of this last day's observations is to the following effect:— At 8 A.M. dense fog all round; frosty: steamed out to get upon bearing of E.S.E. from lighthouse, *i. e.* at right angles to the axial line of the syren and horn.

"At 10.10, supposing that the vessel was not far from the E.S.E. line, and (allowing for the set of the tide and distance run as shown by the patent log) the distance from the lighthouse being apparently near 11 miles, stopped the vessel and heard syren and horn equally powerful, the sounds being thoroughly good and serviceable.

"Mr. TROUGHTON further states that he could locate the position from whence the sound proceeded with the greatest ease, and that he took his bearing from the South Foreland by the aid of the sound alone.

"At this position a wreck-buoy was dropped, the fog being at the time exceedingly thick.

"At 10.18 the fog began to break, and the sounds were not again heard.

"At the Varne light-ship, $12\frac{3}{4}$ miles from the lighthouse, the master reports that from 8 A.M. to 10.30 A.M. they heard the 'horns distinct but not loud.'

"At the South Sand Head light-ship the sounds were plainly heard on Thursday, Friday, and Saturday during the fog."

The results here recorded are of the highest importance, for they bring us face to face with a dense fog and an actual fog-signal, and confirm in the most satisfactory manner the previously recorded observations. The fact of Captain ATKINS and Mr. EDWARDS being awakened by the sound of the syren, proves, beyond all our previous experience, the power of the sound on the 7th of February.

It is important also to note that through the same fog the sounds were well heard at the South Sand Head light-vessel, which is in the opposite direction from the South Foreland, and, as will immediately appear, actually behind the syren.

It is exceedingly interesting to compare the transmission of sound on February 7

with its transmission on October 14, when the wind had the same strength and the same direction, namely N.N.W. with a force of 2. My notes of the observations show that the latter was throughout a day of extreme optical clearness. The range was 10 miles. On February 7 the 'Argus' heard the sound at 11 miles; and it was also heard through the densest fog at the Varne light-vessel, which is $12\frac{3}{4}$ miles from the Foreland.

But this important circumstance is also to be borne in mind: on February 7 the syren happened to be pointed not towards the 'Argus,' but towards Dover. Had the yacht been in the axis of the syren, it is highly probable that the sound might have been heard all the way across to the coast of France.

The fact that Mr. TROUGHTON was able through the fog to "locate" the Foreland, and that his fixing of the direction should be subsequently found correct, is also one of great importance.

Early in the morning of the 20th of February there was also a fog in the neighbourhood of the South Foreland. It was a patchy fog, at intervals very thick and then comparatively clear. The 'Argus' steamed out at 8 A.M., and carried the sounds to a distance of 10 miles along the axial line of the instruments. At that distance the horn-sounds were better than those of the syren, although at shorter distances the syren had greatly excelled the horn. At the Varne light-ship ($12\frac{3}{4}$ miles) the horn-sounds only had been heard during the fog. At the 10-miles position the atmosphere was beautifully clear, the sun shining strongly, and the fog-bank lying over the land clearly defined, extending seaward about 5 miles.

Mr. TROUGHTON states that the sounds of this day were very inferior to those of the much thicker and more homogeneous fog of February 7.

Since the publication of the first notices of this investigation various communications have reached me, to two of which I should like to refer. The Rev. GEORGE H. HETLING, of Fulham, has written to me with a circumstantiality which leaves no room for doubt that he has heard the Portland guns at a distance of 44 miles through a dense fog.

The Duke of ARGYLL has also favoured me with the following very interesting account of his own experience. Coming as it does from a disciplined scientific observer, it is particularly valuable. "This fact" (the permeability of fog by sound) "I have long known, from having lived a great part of my life within four miles of the town of Greenock, across the Frith. Ship-building goes on there to a great extent, and the hammering of the caulkers and builders is a sound which I have been in the habit of hearing with every variety of distinctness, or of not hearing at all, according to the state of the atmosphere; and I have always observed on days when the air was very clear, and every mast and spar was distinctly seen, hardly any sound was heard; whereas on thick and foggy days, sometimes so thick that nothing could be seen, every clink of every hammer was audible, and appeared sometimes as close at hand."

It is hardly necessary for me to say a word to guard myself against the misconception that I consider sound to be assisted by the fog itself. Fog I regard as the visible result

of an act of condensation, which renders homogeneous the acoustically flocculent or turbid air. The fog-particles appear to have no more influence upon the waves of sound than the suspended particles stirred up over the banks of Newfoundland have upon the waves of the Atlantic.

§ 15. *Atmospheric Selection.*

It has been stated in § 3 that the atmosphere on different days shows preferences to different sounds. This point is slightly touched upon in the record of the Serpentine observations; but it is worthy of further illustration.

After the violent shower which passed over us on October 18th, the sounds of all the instruments, as already stated, rose in power; but it was noticed that the horn-sound, which was of lower pitch than that of the syren, improved most, at times not only equalling, but surpassing the sound of its rival. From this it might be inferred that the atmospheric change produced by the rain favoured more especially the transmission of the longer sonorous waves.

But our programme enabled us to go further than mere inference. It had been arranged that up to 3.30 P.M. the syren should perform 2400 revolutions a minute, generating 480 waves a second. As long as this rate continued, the horn, after the shower, had the advantage. The rate of rotation was then changed to 2000 a minute, or 400 waves a second, when the syren-sound immediately surpassed that of the horn. A clear connexion was thus established between aërial reflection and wave-length.

The 10-inch Canadian whistle being capable of adjustment so as to produce sounds of different pitch, on the 10th of October I ran through a series of its sounds. The shrillest appeared to possess great intensity and penetrative power. The belief that a note of this character (which affects so powerfully, and even painfully, an observer close at hand) has also the greatest range is a common one. Mr. A. GORDON, in his examination before the Committee on Lighthouses in 1845, expressed himself thus:—"When you get a shrill sound, high in the scale, that sound is carried much further than a lower note in the scale." I have heard the same opinion expressed by other scientific men.

On the 14th of October the point was submitted to an experimental test. It had been arranged that up to 11.30 A.M. the Canadian whistle, which had been heard with such piercing intensity on the 10th, should sound its shrill note. At the hour just mentioned we were beside the Varne buoy, 7¾ miles from the Foreland. The syren, as we approached the buoy, was heard through the paddle-noises; the horns were also heard, but more feebly than the syren. We paused at the buoy and listened for the 11.30 gun. Its boom was heard by all. Neither before nor during the pause was the shrill-sounding Canadian whistle once heard. It was now adjusted to produce its ordinary low-pitched note, which was immediately heard. Still further out the low boom of the cannon continued audible after all the other sounds had ceased.

But it was during the early part of this day only that this preference for the longer

waves was manifested. At 3 P.M. the case was completely altered, for then the high-pitched syren was heard when all the other sounds were inaudible. On many other days we had illustrations of the varying comparative power of the syren and the guns. On the 9th of October sometimes the one, sometimes the other was predominant. On the morning of the 13th the syren was clearly heard on Shakespeare's Cliff, where two guns with their puffs perfectly visible were unheard. On October 16, 2 miles from the signal-station, the gun at 11 o'clock was inferior to the syren, but both were heard. At 12.30, the distance being 6 miles, the gun was quite unheard, while the syren continued faintly audible. Later on in the day the experiment was twice repeated. The puff of the gun was in each case seen, but nothing was heard; in the last experiment, when the gun was quenched, the syren sent forth a sound so strong as to maintain itself through the paddle-noises. The day was clearly hostile to the passage of the longer sonorous waves. I may anticipate matters so far as to say that on this day the syren heard at Shakespeare's Cliff surpassed the gun, while at the South Sand Head light-vessel the gun surpassed the syren. In the former case a light wind opposed, and in the latter case favoured the sound; and the opposition of the wind proves in all cases more damaging to the gun than to the syren.

October 17 began with a preference for the shorter waves. At 11.30 A.M. the mastery of the syren over the gun was pronounced; at 12.30 the gun slightly surpassed the syren; at 1, 2, and 2.30 P.M. the gun also asserted its mastery. This preference for the longer waves was continued on October 18. On October 20 the day began in favour of the gun, then both became equal, and finally the syren gained the mastery: but the day had become stormy, which is always a disadvantage to the momentary gun-sound. The same remark applies to the experiments of October 21. At 11 A.M., distance 6½ miles, when the syren made itself heard through the noises of wind, sea, and paddles, the gun was fired; but, though listened for with all attention, no sound was heard. Half an hour later the result was the same. On October 24 five observers saw the flash of the gun at a distance of 5 miles, but heard nothing; all of them at this distance heard the syren distinctly: a second experiment on the same day yielded the same result. On the 27th also the syren was triumphant; and on three several occasions on the 29th its mastery over the gun was still more pronounced. Such experiments yield new conceptions as to the scattering of sound in the atmosphere. No sound here employed is a simple sound; in every case the fundamental note is accompanied by others, and the action of the atmosphere on these different groups of waves probably has its optical analogue in that scattering of the light-waves which produces the various shades and colours of the sky.

I have just glanced at the observations made on October 17; but, as this proved our day of maximum acoustic transparency, I will here introduce a fuller record of the day's proceedings. Mr. HOLMES having expressed a wish to sound his four horns together, the day was devoted to comparing them with the syren. The barometer had been rising during the whole of the previous day, the wind being W.S.W. This

morning we had a light air from the N.E., force 1. Haze over the sea; not deep, for the sun shone through it: water very smooth.

About a quarter of a mile from the pier end, and at 2·6 miles from the station, we waited, and heard distinctly the tuning of the horns. Never previously had they been heard so loud in this position—a result plainly due to the shifting of the wind.

At 10 A.M. the gun was good; the horn was also good, voluminous and musical; the syren was very loud, hard and penetrating. This was the result of repeated observations.

Steamed towards Dover Castle into the sound-shadow, on entering which all the sounds were greatly enfeebled; but the syren, though vastly fallen, remained distinctly superior to the four horns.

We manned the gig and rowed towards the shore. Halted near the end of East Cliff Terrace, where the horns and the syren were audible, but barely so. The sounds at times rose and sank in power, so that after one had been set down as barely audible, a succeeding blast rendered a qualification of the statement necessary. The sound appeared to be a little feebler at some distance from the beach than close to the beach itself.

It was rendered certain by these observations that the four horns, two of which were on the summit and two at the base of the cliff, had in the sound-shadow no advantage over the syren.

A gun was fired at 10.30; but we were not attending to it, and no one in the gig heard it. In the 'Galatea,' a quarter of a mile nearer the edge of the acoustic shadow, the report was heard as a feeble thud. Admiral COLLINSON, however, thought it had an advantage over the syren.

Steamed round the Foreland along an arc of 2 miles radius. I happening to be in the deck-cabin, heard there a sudden and powerful augmentation of the sound of both syren and horns; at the same moment Mr. EDWARDS came to me to announce that the 'Galatea' had just cleared the sound-shadow, the instruments being in sight. The shadow was therefore sharply defined. This sharpness was repeatedly observed on both sides of the Foreland.

Steamed towards the axis; but before we reached it the syren-sounds rose to an extraordinary degree of power, the horns yielded a full and mellow sound, far, however, below the syren in intensity; both were well heard through the noise of the paddles.

At 11 A.M. near the axis, distance 2 miles, the gun was fired, and yielded a very loud report. Steamed out along the axis; for a time both horns and syren were heard through the paddle-noises, but at 3 miles distance the horn-sounds vanished from the hearing of some, while a feeble murmur from them continued to be heard by others. To all, however, the syren was by far the clearest sound.

At 11.30, our distance being $5\frac{1}{2}$ miles, the gun was fired, but no sound was heard. At this hour the gun was clearly mastered by the syren. At 7 miles distance, the paddles still going, the syren yielded a distinctly serviceable sound: to a sailing-vessel

it would be still more serviceable. At $7\frac{3}{4}$ miles the sound of the syren practically vanished.

Halted at 8 miles and listened: the syren was faintly heard, and after a little time seemed to rise in power. This has been an almost daily experience. After the stoppage of the paddles the ear appears to require a little time to recover its entire sensitiveness.

It may be questioned whether the change of intensity in passing from 7 to $7\frac{3}{4}$ miles was due to the increase of distance alone. It was probably due to the passage of an invisible acoustic cloud; as we waited, not only did the sound of the syren rise in power, but that of the horns became distinctly audible.

At 12.0 the gun was fired, and 46″ afterwards a faint but perfectly distinct report was heard.

Steamed on, the air being very light and the water very smooth. A thin haze overspread the whole surface of the sea, the horizon not being so sharp nor the coast of France so visible as they were yesterday. At 9 miles we stopped and listened. Both the French and English coasts were very dim with haze; the sun, however, was shining. From the bridge of the 'Galatea' occasional tones of the syren of the faintest character were heard; from the stern of the vessel the syren-sounds were also heard, but they were exceedingly faint. Once or twice the murmur of the horns was feebly heard; but on one occasion they rose to positive distinctness, this being entirely due to the varying state of the air.

At 12.30 we saw the puff of the gun, and 50″ afterwards, the distance being 9·2 miles, heard a faint but distinct report: the gun-sound here was better than that of the syren.

Stopped at 10 miles. From the stern of the vessel both syren and horns were heard as plainly as at 9 miles; if any thing, more plainly.

At 11 miles both syren and horns were faintly heard, a little more faintly than on the last occasion, but still quite distinct. Up to this point the sea had been of glassy smoothness; it now became very slightly ruffled. The horns on this day and at this distance seemed at times equal to the syren; at times, however, inferior to it.

At 1 P.M. a gun was fired. The report was fair, and much beyond the intensity of the syren; the day had evidently become favourable to the transmission of the longer sonorous waves.

Stopped at 15 miles. From the stern of the vessel Mr. DOUGLASS and myself heard distinctly the very faint report of the 1.30 gun. A little afterwards guns fired at Dover were distinctly heard. We learned subsequently that they had been employed in target practice. We waited and listened for some time at 15 miles distance: both horns and syren were heard occasionally.

A little after 2 P.M. we heard a dull report, exactly answering to our time of firing; but half a minute afterwards we heard a second similar report from one of the guns at Dover. Distance about $16\frac{1}{2}$ miles, near Quenocs buoy, in front of Cape Blanc Nez. Besides the gun, nothing was here audible. This was the maximum acoustic range attained during this inquiry.

§ 16. *Action of Wind.*

The action of wind upon sound has been frequently observed, and a statement of Dr. ROBINSON'S regarding it has been already quoted (§ 2). In stormy weather we were frequently forsaken by our steamer, which had to seek shelter in the Downs or Margate Roads, and on such occasions the opportunity was turned to account to determine the effect of the wind. On October 11, accompanied by Mr. DOUGLASS and Mr. EDWARDS, I walked along the cliff from Dover Castle towards the Foreland, the wind blowing strongly against the sound. On the Dover side of the Cornhill Coastguard Station (see Map, Plate XIX.), and at about a mile and a half from the Signal-Station, on the edge of a deep hollow or combe, we first heard the faint but distinct sound of the syren. The horn-sound was inaudible. A gun fired during our halt was also unheard.

Descending the combe the syren-sound vanished as we plunged more deeply into the acoustic shadow. On the eminence close to the Coastguard Station the wind was very violent and noisy; sheltering ourselves as well as we could behind some mounds, we listened for the sounds, but heard nothing. No sounds had been heard during the day by the coastguard men.

At the edge of the next combe we caught the sound of the syren, which continued to be heard as we walked round the combe. As we approached the station we saw the smoke of the gun. Mr. EDWARDS heard a faint crack, but neither Mr. DOUGLASS nor myself heard any thing. The sound of the syren was at the same time of piercing intensity.

We waited at this spot for ten minutes, when another gun was fired. I thought I heard a faint thud, but could not be certain. My companions heard nothing. On pacing the distance afterwards it was found to be only 550 yards. We were shaded at the time by an eminence from both the syren and the gun, and more deeply shaded from the latter than from the former; but the difference could not account for the utter extinction of the gun-sound at a time when the syren sent to us a note of great power. Subsequent experiments, moreover, confirmed the conclusion to which this one points, that an opposing wind affects the gun-sound far more seriously than that of the syren.

Requesting Mr. AYRES to walk to windward along the cliff and to note and report upon the sounds, and asking Mr. DOUGLASS to proceed to St. Margaret's Bay, during their absence I had 3 guns fired. Mr. AYRES heard only one of them. Favoured by the wind, Mr. DOUGLASS, at twice the distance, and far more deeply immersed in the sound-shadow, heard all three reports with the utmost distinctness.

Joining Mr. DOUGLASS, we continued our walk to a distance of $\frac{3}{4}$ of a mile beyond St. Margaret's Bay. Here, being dead to leeward, though the wind was as violent as it had been at the coastguard station, the sound of the syren was borne to us with extraordinary power*. In this position we also heard the gun loudly, and two other loud reports at the proper interval of ten minutes, as we returned to the Foreland.

To windward of the instruments, Mr. EDWARDS noticed a rapid and considerable falling

* The horn here was temporarily suspended, but doubtless would have been well heard.

off of the syren-sound. As far as the first combe the sound was fairly heard; he lost it in descending into the hollow, and recovered it in ascending the opposite slope. It accompanied him, being of variable strength and sometimes unheard, as far as the Coastguard Station. Mr. EDWARDS heard no guns. It is within the mark to say that the gun to-day was heard to leeward five times, and might have been heard fifteen times, as far as to windward.

In windy weather the shortness of its sound is a serious drawback to the use of the gun as a signal. In the case of the horn and syren, time is given for the attention to be fixed upon the sound; and a single puff, while cutting out a portion of the blast, does not obliterate it wholly. Such a puff, however, may be fatal to the momentary gun-sound.

The latter, moreover, is less distinguishable from the sound of the wind in the ears than is the sound of the syren. This action was well illustrated on October 22. We halted near the Cornhill Coastguard Station, and the wind blowing from W.S.W. being very noisy, I sheltered myself behind a bank and listened. The horn and the syren were about equal in power, neither of them being strong. The 3 P.M. gun was fired: the smoke was seen, but no sound was heard. We then sheltered ourselves behind the washhouse of the station, where the horn and the syren, which had been audible behind the bank, rose not only to great distinctness but to great power. The horn was sometimes particularly strong; the syren had the air of being more distant, which may in part arise from the admixture of its really distant echoes with the direct sound.

A gun fired while we were in the shelter of the washhouse produced a loud report; it was the first time during the day that the coastguardsman who was present had heard the gun. Accompanied by Mr. EDWARDS I returned to the shelter of the bank, where the report had previously escaped me. Corresponding to the known time of firing, I heard a faint thud; he heard nothing. The syren and horns were powerful at the time.

But the ears only required to be defended to render the gun effective. The 3.30 report was loud to Mr. DOUGLASS and Mr. EDWARDS, who stood in shelter of the washhouse, whereas it was unheard by me who stood out in the wind. On changing places with Mr. DOUGLASS, Mr. EDWARDS and I heard a loud report of the next gun; to Mr. DOUGLASS it was barely audible. Mr. EDWARDS now went outside, while Mr. DOUGLASS and I remained in shelter. We heard the 3.50 gun distinctly though not loudly; by Mr. EDWARDS it was unheard. These experiments illustrate the serious effect which local noises may have upon a signal-sound, particularly that of a gun.

At 4 P.M., near the edge of the combe beyond the coastguard station, we lay down in shelter of a furze bush. Here we heard the sounds of syren and horns distinctly but faintly; the gun was not heard. This position was 450 yards beyond the coastguard station. We then walked from the coastguard station through the fields towards the signal-station; both syren and horns sounded clear and loud. At 4.10 P.M. a gun was fired, but

it was not heard. At 4.20 we halted at the side of the combe nearest the signal-station. Here to me the report of the gun was fairly loud, but not loud to my companions.

Wishing to ascertain how the sound fared to leeward, we followed the line of coast to St. Margaret's Bay and reached the summit of the cliff above and a little beyond the coastguard station. Both the syren and the horn sent their sounds to us with extraordinary power. The gun fired at 4.50 was also very loud, though the distance far exceeded that at which the gun-shots had become entirely inaudible to windward.

As we returned we heard several shots which were of a totally different character from those heard at the same distance to windward of the signal-station; they were sharp and dense, while the others resembled the shock of a soft body against sheet iron.

On October 23 Mr. DOUGLASS, at my request, was good enough to explore the atmosphere from the Foreland towards Deal, while Mr. AYRES undertook the observations on the Dover side of the Foreland. The wind, with a force of 6 to 8, blew from the W. and W.S.W. The instruments in use were the syren, the two upper horns, and the howitzer. They were all pointed southwards.

In the case of Mr. AYRES, at 600 paces from the station the syren was heard distinctly, the horns indistinctly and only occasionally; the gun was unheard. Between this point and another, 440 paces west of the Coastguard Station, or about $1\frac{1}{4}$ mile west of the instruments, eight observations were made at different points. In three cases only was the gun heard; in three only were the horns heard occasionally and faintly; in all cases the syren was heard. Against the wind the superiority of the syren over the horns, and more especially over the gun, is incontestable.

At Ringwold, on the other side of the Foreland, distant 3 miles, and at Walmer, distant $3\frac{2}{3}$ miles, the gun yielded a loud report; the syren and horns also yielded a good sound. Near Deal barracks, $4\frac{1}{2}$ miles, near the railway station, 5 miles, and near Sholden church, $5\frac{1}{2}$ miles, the gun yielded a fair report: the syren was heard, being about equal to the gun. At 6 miles distance the gun was heard, but very feebly; at $6\frac{3}{4}$ miles and at $7\frac{1}{3}$ miles neither gun nor horn was heard, while in both cases the syren was audible. On the Sandwich side of the Foreland, therefore, the sounds on this day were heard at least four times as far as on the Dover side, while in both directions the syren was furthest heard.

On the 24th the wind shifted to E.S.E., and the sounds, which when the wind was W.S.W. failed to reach Dover, were now heard in the streets through thick rain. On the 27th the wind was E.N.E. In our writing-room in the Lord Warden Hotel, in the bedrooms, and on the staircase the sound of the syren reached us with surprising power, piercing through the whistling and moaning of the wind, which blew through Dover towards Folkestone. The sounds were heard at 6 miles from the Foreland on the Folkestone road; and had the instruments not then ceased sounding they might have been heard much further. At the South Sand Head light-vessel, on the opposite side, no sound had been heard throughout the day. On the 28th, the wind being N. by E., the sounds

were heard in the middle of Folkestone, while in the opposite direction they failed to reach the South Sand Head light-vessel. On the 29th the limits of range were Eastware Bay on the one side and Kingsdown on the other; on the 30th the limits were Kingsdown on the one hand and Folkestone Pier on the other. With a wind having a force of 4 or 5 it was a very common observation to hear the sound in the one direction three times as far as in the other*.

It may be worthy of note that within twenty yards or so of the gun the sound was so intense as to render it necessary, prior to each shot, to remove a barometer which hung on the side of the wooden shed containing the horns of Mr. HOLMES. On one occasion, when this precaution was neglected, the barometer was broken by the concussion. Neither horns nor syren appear to affect the instrument perceptibly. Still, notwithstanding this initial *vis viva*, the gun-sound is often overmatched at a distance by both syren and horns.

§ 17. *Influence of Pitch and Pressure.*

On October 18 experiments were made in which the steam-pressure was varied with a constant pitch, and others in which the pitch was varied with a constant pressure. At a distance of 3 miles from the shore the intensities corresponding to 40 lbs. and 80 lbs. pressure respectively did not differ from each other as much as might have been expected. With a pressure of 40 lbs. the sound was very fine; with a 50-lbs. pressure it was also very fine, and perceptibly *harder*; with a pressure of 60 lbs. it differed but little from that of 50; with a pressure of 70 lbs. the sound was harder and firmer than the last; the difference between 70 and 80 lbs. was scarcely perceptible.

* In vol. i. of the 'Annales de Chemie' for 1816, p. 176, ARAGO introduces a memoir by DE LA ROCHE, then recently deceased, in these words:—" L'auteur arrive à des conclusions, qui d'abord pourront paraître paradoxales, mais ceux qui savent combien il mettait de soins et d'exacitude dans toutes ses recherches se garderont sans doute d'opposer une opinion populaire à des expériences positives." DE LA ROCHE's paper was " On the Influence exerted by the Wind on the Propagation of Sound;" and the strangeness of his results consisted in his establishing, by quantitative measurements, not only that sound has a greater range in the direction of the wind than in the opposite direction, but that the range at right angles to the wind is the greatest of all.

The only attempt to account for DE LA ROCHE's results theoretically is due to Professor STOKES. In a short but exceedingly able communication presented to the British Association in 1857, this eminent physicist points out a true cause which, *if sufficient*, would account for the results referred to. The lower atmospheric strata are retarded by friction against the earth, and the upper ones by those immediately below them; the velocity therefore increases from the ground upwards. This difference of velocity throws the sound-wave upwards in a direction opposed to the wind, and downwards in a direction coincident with the wind. In this latter case the direct wave is reinforced by the wave reflected from the earth. Now the reinforcement is greatest in the direction in which the direct and reflected waves inclose the smallest angle—that is, at right angles to the direction of the wind; hence the greater range in this direction. It is not therefore, according to Professor STOKES, a stifling of the sound to windward, but a tilting of the sound-wave over the heads of the observers that defeats the propagation in that direction.

This explanation calls for verification, and I wished much to test it by means of a captive balloon rising high enough to catch the deflected wave; but on communicating with Mr. COXWELL, who has earned for himself so high a reputation as an aëronaut, I learned with regret that the experiment was too dangerous to be carried out.

In determining the influence of pitch, the rate of revolution was varied from 1500 to 2400 a minute. The sound in all cases was very fine, but that corresponding to the most rapid rate of revolution seemed the best and most penetrating. Though these experiments were made at distances of 2 and 3 miles from the shore, distinct and long-continued echoes followed every syren-blast, coming to us from a bearing directly opposed to that of the signal-station.

I have already mentioned October 17 as our day of maximum acoustic transparency; the transparency continued to some extent during the 18th; for on this day, while halting at a distance of 3 miles from the station, we heard the loud report, not of cannon, but apparently of musketry on shore. The sounds were afterwards traced to rifle practice on Kingsdown beach. The day was optically far less favourable than July 3, but each rifle made itself distinctly heard to twice the distance at which an 18-pounder failed to be heard on the 3rd of July.

Arrangements having been made to enable the syren to be pointed in different directions, November 21 and the two subsequent days were devoted to the investigation of both it and the gun, with reference to the direction of their axes. The sonorous waves surrounding the gun proved to be of almost equal intensity throughout, very little difference being observed between the sound when the gun was pointed at us, and when it was pointed at right angles to the line joining it and us. In the syren, however, the intensity in the axis was markedly superior to the intensity at right angles to the axis. This is what might be expected; for the syren-trumpet being expressly intended to project the sound in a certain direction, it can only do this by withdrawing it from other directions.

§ 18. *Concluding Remarks.*

A few additional remarks and suggestions will fitly wind up this paper. It has been proved that in some states of the weather the howitzer firing a 3-lb. charge commands a larger range than the whistles, trumpets, or syren. This was the case, for example, on the particular day, October 17, when the ranges of all the sounds reached their maximum.

On many other days, however, the inferiority of the gun to the syren was demonstrated in the clearest manner. The gun-puffs were seen with the utmost distinctness at the Foreland, but no sound was heard, the note of the syren at the same time reaching us with distinct and considerable power.

The disadvantages of the gun are these:—

a. The duration of the sound is so short that, unless the observer is prepared beforehand, the sound, through lack of attention rather than through its own powerlessness, is liable to be unheard.

b. Its liability to be quenched by a local sound is so great that it is sometimes obliterated by a puff of wind taking possession of the ears at the time of its arrival. This point was alluded to by ARAGO, in his report on the celebrated experiments of 1822. By such a puff a momentary gap is produced in the case of a continuous sound, but not entire extinction.

c. Its liability to be quenched or deflected by an opposing wind, so as to be practically useless at a very short distance to windward, is very remarkable. A case has been cited in which the gun failed to be heard against a violent wind at a distance of 550 yards from the place of firing, the sound of the syren at the same time reaching us with great intensity.

Still, notwithstanding these drawbacks, I think the gun is entitled to rank as a first-class signal. I have had occasion myself to observe its extreme utility at Holyhead and the Kish light-vessel. The commanders of the Holyhead boats, moreover, are unanimous in their commendation of the gun. An important addition in its favour is the fact that the flash often comes to the aid of the sound: on this point the evidence cited in the Appendix is quite conclusive.

There may be cases in which the combination of the gun with one of the other signals may be desirable. Where it is wished to confer an unmistakable individuality on a fog-signal station, such a combination might with advantage be resorted to.

If the gun be retained as one form of fog-signal (and I should be sorry, at present, to recommend its total abolition) it ought to be of the most suitable description. Our experiments prove the sound of the gun to be dependent on its shape; but we do not know that we have employed the best shape. This suggests the desirability of constructing a gun with special reference to the production of sound*.

An absolutely uniform superiority on all days cannot be conceded to any one of the instruments subjected to examination; still our observations have been so numerous and long-continued as to enable us to come to the sure conclusion that, on the whole, the steam-syren is, beyond question, the most powerful fog-signal which has hitherto been tried in England. It is specially powerful when local noises, such as those of wind, rigging, breaking waves, shore-surf, and the rattle of pebbles, have to be overcome. Its density, quality, pitch, and penetration render it dominant over such noises after all other signal-sounds have succumbed.

I have not, therefore, hesitated to recommend the introduction of the syren as a coast signal.

It will be desirable in each case to confer upon the instrument a power of rotation, so as to enable the person in charge of it to point its trumpet against the wind or in any other required direction. This arrangement has been made at the South Foreland, and it presents no mechanical difficulty. It is also desirable to mount the syren so as to permit of the depression of its trumpet fifteen or twenty degrees below the horizon.

In selecting the position at which a fog-signal is to be mounted, the possible influence of a sound-shadow, and the possible extinction of the sound by the interference of the direct waves with waves reflected from the shore, must form the subject of the gravest consideration. Preliminary trials may, in most cases, be necessary before fixing on the precise point at which the instrument is to be placed.

The syren, it will be remembered, has been hitherto worked with steam of 70 lbs.

* The Elder Brethren have already acted upon this suggestion, and have had plans of a new signal-gun laid before them by the constructors of the War Department.

pressure or thereabouts: the trumpets have been worked with compressed air; and our experiments have proved that a pressure of 20 lbs. yielded sensibly as loud a sound as higher pressures. The possibility of obtaining a serviceable sound with this low air-pressure may render the employment of caloric engines available with trumpets: if so, the establishment of trumpets on board light-vessels would be greatly facilitated. The signals at present existing on board such vessels are very inefficient, and may, I think, be immeasurably improved upon. There are, I am told, practical difficulties as to the introduction of steam on board light-ships; otherwise I should be strongly inclined to recommend the introduction among them of the Canadian whistle. The syren would probably be found too large and cumbrous for light-vessels.

The form of the syren which has been long known to scientific men is worked with air, and it would be worth while to try how the fog-syren would behave supposing compressed air to be substituted for steam. Compressed air might also be tried with the whistles. Such experiments, to render them comparable with our previous ones, ought to be made at the South Foreland.

No fog-signal hitherto tried is able to fulfil the condition laid down by Dr. ROBINSON, in the very able letter already quoted in § 2, namely, "*that all fog-signals should be distinctly audible for at least 4 miles, under every circumstance.*" Circumstances may exist to prevent the most powerful sounds from being heard at half this distance. What may with certainty be affirmed is, that in almost all cases the syren may certainly be relied on at a distance of 2 miles; in the great majority of cases it may be relied upon at a distance of 3 miles, and in the majority of cases to a distance greater than 3 miles.

Happily the experiments thus far made are perfectly concurrent in indicating that at the particular time when fog-signals are needed, that is during foggy weather, the air in which the fog is suspended is in a highly homogeneous condition; hence it is in the highest degree probable that in the case of fog we may rely upon these signals being effective at far greater distances than those just mentioned.

I say "probable," while the experiments seem to render this result certain. Before pronouncing it so, however, I should like to have some experience of warmer fogs than those in which the experiments have hitherto been made. That the fog-particles themselves are not sensibly injurious to the sound has been demonstrated; but it is just possible that in warm weather the air associated with the fog may not be homogeneous. It will probably be found so, but I would recommend the experiment to be made on some of the fogs of the early summer.

I am cautious not to inspire the mariner with a confidence which may prove delusive. When he hears a fog-signal he ought, as a general rule (at all events until extended experience justifies the contrary), to assume the source of sound to be not more than 2 or 3 miles distant, and to take precautions accordingly.

Once warned, he may, by the heaving of the lead or some other means, be enabled to check his position. But if he errs at all in his estimate of distance, it ought to be on the side of safety.

Unless strong practical reasons be adduced in its favour, I should deprecate a

len thened interval between the blasts of the trumpet or syren. My own small experience as a sailor has shown me how harassing to the mariner are some of our revolving lights with a long period of rotation. No light, in my opinion, ought to be obscured for a period exceeding 30 seconds; and the interval between two blasts of our fog-signal ought, in general, not to be longer.

With the instruments now at our disposal, wisely established along coasts, I venture to think that the saving of property in ten years will be an exceedingly large multiple of the outlay necessary for the establishment of such signals. The saving of life appeals to the higher motives of humanity.

In a Report written for the Trinity House on the subject of fog-signals, my excellent predecessor, Professor FARADAY, expresses the opinion that a false promise to the mariner would be worse than no promise at all. Casting our eyes back upon the observations here recorded, we find the sound-range on clear, calm days varying from $2\frac{1}{2}$ miles to $16\frac{1}{2}$ miles. It must be evident that an instruction founded on the latter observation would be fraught with peril in weather corresponding to the former. Not the maximum but the minimum sound-range should be impressed upon the mariner. Want of attention to this point may be followed by disastrous consequences.

This remark is not made without cause. I have before me a Notice to Mariners issued by the Board of Trade regarding a fog-whistle recently mounted at Cape Race, and which is reputed to have a range of 20 miles in calm weather, 30 miles with the wind, and in stormy weather or against the wind 7 to 10 miles. Now, considering the distance reached by sound in our observations, I should be willing to concede the possibility, in a more homogeneous atmosphere than ours, of a sound-range on *some* calm days of 20 miles, and on *some* light windy days of 30 miles to a powerful whistle; but I entertain a strong belief that the stating of these distances, or of the distance 7 to 10 miles against a storm, without any qualification, is simply calculated to inspire the mariner with a false confidence which may lead him to ruin. I would venture to affirm that at Cape Race calm days might be found in which the range of the sound will be less than one fourth of what this notice states it to be. Such publications do not fulfil their proper object if they are made the vehicle by which inventors vaunt the performance of their instruments; they ought to be without a trace of exaggeration, and furnish only data on which the mariner may with perfect confidence rely. The object which I had in view in extending these observations over so long a period was to make evident to all how fallacious it would be, and how mischievous it might be, to draw general conclusions from observations made in weather of great acoustic transparency. The mariner when he hears a fog-signal ought, as just stated, to assume the minimum rather than the maximum distance, and to take his measures accordingly.

Thus ends, for the present at all events, an inquiry which I trust will prove of some importance, scientific as well as practical. In conducting it I have had to congratulate myself on the unfailing aid of the Elder Brethren of the Trinity House. Captain DREW, Captain CLOSE, Captain WERE, Captain ATKINS, and the Deputy Master have all from

time to time taken part in the inquiry. To the eminent arctic navigator Admiral COLLINSON, who showed throughout unflagging and, I would add, philosophic interest in the investigation, I am indebted for most important practical aid: he was almost always at my side, comparing opinions with me, placing the steamer in the required positions, and making with consummate skill and promptness the necessary sextant observations. I am also deeply sensible of the important services rendered by Mr. DOUGLASS, the able and indefatigable Engineer, of Mr. AYRES, the Assistant Engineer, and of Mr. PRICE EDWARDS, the Private Secretary of the Deputy Master of the Trinity House.

The officers and gunners at the South Foreland also merit my best thanks, as also Mr. HOLMES and Mr. LAIDLAW, who had charge of the trumpets, whistles, and syren.

In the subsequent experimental treatment of the subject I have been most ably aided by my excellent assistant, Mr. JOHN COTTRELL.

APPENDIX.

On Gun-flashes as Fog-signals.

In crossing to Ireland to witness experiments instituted by the Board of Irish Lights, I have usually questioned the intelligent and courteous captains of the steamers plying between Holyhead and Kingstown regarding the coast-signals. I was distinctly informed by some of them that in fogs so thick as entirely to quench the powerful revolving light of the South Stack, the flash, or rather the glare upon the fog, produced by the gun at the North Stack was usually visible and of great utility. Bearing upon this remarkable point I have been favoured with the following letter from Captain GALWAY, which seems well worthy of insertion here:—

"November 27, 1873.

"DEAR SIR,—Mr. WIGHAM having communicated to me a wish expressed by you to have an account of an observation of mine with respect to the fog-gun on Lundy Island, in the Bristol Channel, I have much pleasure in forwarding you a detailed account of the circumstance, and beg to say that I feel gratified that you should think the observation worthy of your notice. I was on board the Bristol Steam Navigation Company's steamer 'Inverna,' on a passage from Waterford to Bristol, on Sept. 9 last. We left Waterford at 8 A.M., and at 11.10 A.M. were abreast of the 'Conningbed' light-ship. When we took our departure and shaped a course S.E. by S. ½ S. to pass a short way to the westward of the Smalls, or failing seeing them (the weather being thick) to make Lundy Island, we put the patent log over at the same time. The weather was thick, wind W.S.W., with drizzling rain. At 3 P.M. we were keeping a look-out for the Smalls lighthouse, but were unable to see it owing to the thickness of the weather. At 8 P.M., estimating that we had run our distance, we hauled in the patent log and found that it registered 84 miles, the distance being 90 miles. We therefore thought we must be near Lundy Island, and were peering into the fog, looking out anxiously for the light. I suggested to the captain that he should keep away a little up the Channel in order to bring the gun more to windward. This we did, and about ten minutes afterwards we observed a flash as that of a gun bearing about south. I noted the time, 8.15 P.M., G.M.T., and remarked that I thought it must be the gun on Lundy, but could not understand our not being able to see the light. The weather at the time was thick, occasionally clearing and then thickening over again, with light showers of rain quite obscuring the horizon. I had remarked to the captain just before that I did not think he could see a first-class light for more than a mile. I watched the time, as I was not sure of the intervals at which the gun was fired and had no Admiralty List of Lights on board, and the chart the captain had did not give the required information. I felt certain, however, that it was either fifteen or seventeen minutes; and at 8.31 P.M. I again observed the flash: this time I was satisfied that I heard a slight concussion, but I am sure I should not have perceived it had not my attention been riveted to the spot by the flash. The vessel was also more to *leeward of the gun* and the *engines stopped*. At 8.45 I again saw the flash distinctly and caught a slight reverberation, and a few minutes afterwards (the fog lifting a little) we observed

the light very faintly and with a red appearance through the fog. However, having satisfied ourselves of our position and that the light was Lundy Island (by intervals of revolution), we steamed a course for the Nash Lights, which we made in due time, the night having become clear.

"In my narrative of the circumstance I say *we*, as although I was not in any way officially connected with the vessel, the captain, who had not been on this line for many years, knowing that I was in the habit of close coast navigation and that I had a good deal of experience in making lights, appealed to me for advice. I need scarcely add that I feel very much pleased that you think my observations worthy of your notice.

"I am, dear Sir,
"Yours faithfully,
"A. Knox Galway.

"N.B.—I am unable to say what position the gun is in from the lighthouse, as neither the Admiralty List of Lights or Chart gives it, but I feel quite sure that the Trinity House will give you that information."

The following letter, in reply to an inquiry instituted by Mr. Wigham at my request, is from the commander of the 'Ulster' Royal Mail Packet, and is dated Kingstown, Nov. 23, 1873:—

"Sir,—In answer to your inquiry I beg to say that I have found the guns stationed on the Kish Light and the North Stack lighthouse to be of great service to me in thick weather when approaching the harbours of Kingstown and Holyhead respectively. When the lights of the light-ship and of the Stack lighthouse have been quite invisible by reason of the density of the fog, I have distinctly seen the flash of the gun, making, as it were, an impression on the fog and indicating quite plainly the position in which the gun was placed. In some cases I have been able to see the flash when no sound from the gun has reached me, and I am therefore of opinion that the more brilliant such flashes could be made the better for maritime purposes.

"I am, yours truly,
"Richard S. Triphook,
"Commander 'Ulster' Royal Mail Packet."

From Captain Kendall, Commander of the 'Connaught,' the following letter has been received:—

"Kingstown, December 1, 1873.

"Sir,—In reply to your inquiry I beg to inform you that I have several times seen the flashes from the guns at the Kish light-ship and at the North Stack lighthouse, when, owing to dense fogs, the lights themselves have been invisible. These flashes have thus proved very useful to me by showing me clearly my position. On various occasions I have perceived the flash of the gun when I could not hear its sound. In my opinion these gun-flashes are very advantageous to seamen, and of course it is very desirable that they should be as vivid as possible.

"I am, Sir,
"Your obedient Servant,
"T. E. Kendall,
"Commander R.M.S. 'Connaught.'"

From the Commander of the 'Leinster' the following letter has been received:—

"December 1, 1873.

"Sir,—I beg to inform you that the gun at the Kish light-ship and also that at the North Stack lighthouse have been of very great advantage to me in foggy weather. I have on several occasions seen the flashes of these guns when the light in the lighthouse has been entirely obscured owing to the thickness of the weather, and thus their bearings have been clearly pointed out to me. Frequently I have seen the flash of the gun, although unable to hear its report. It is evident that the brighter these flashes can be made, the more useful they will prove to be.

"I am,
"Your obedient Servant,
(Signed) "Charles John Slaughter,
"Commanding R.M.S. 'Leinster.'"

The point referred to in these letters is, I think, one of practical importance. The intensity of the light is due to the concentration of the combustion of a considerable amount of matter into the fraction of a second of time. It is a question well worthy of consideration whether on board light-ships and elsewhere the combustion of a definite amount of gunpowder, or of gun-cotton, at definite intervals during fog may not turn out to be a simple and useful form of signal. The combustion, of course, would in this case be effected with a view to the production of the maximum light instead of the maximum sound.

In dealing with this subject the gas-gun proposed by Mr. WIGHAM would naturally be considered.

Remark added, May 27.—The more I think of it, and the more I experiment upon it, the more important does this question of flashes appear to me. In one of the sections of the foregoing paper experiments on artificial fogs are described. The densest of these were suddenly and strikingly illuminated throughout by the combustion of half a grain of gunpowder, and of a still smaller quantity of gun-cotton. The cutting off and restoration of the candle-light, or the electric light, used to test the density of the fog, produced a similar effect. It is its suddenness that renders the lightning-flash so startlingly vivid through a cloud. A revolving light like the South Stack does not fulfil the necessary conditions. Its revolution is slow, and the angular spaces between the beams being filled by laterally scattered light, the differential action is practically abolished. At a distance the luminosity, when uniform, may be so feeble as to be unseen, while its sudden extinction and revival would render it sensible.

Remarkable Instances of Acoustic Opacity.

In his excellent lecture entitled "Wirkungen aus der Ferne," DOVE has collected some striking cases of the interception of sound. During the battle of Cassano on the Adda, between the Duc de Vendôme and the Prince Eugene, an army corps stationed under the Duke's brother five miles up the river failed to join the battle through not hearing the cannonade. In a river-valley, particularly on a warm day, it would, in my opinion, be perilous to place much dependence upon sound. Near Montereau on the Seine, during the battle between Napoleon I. and the King of Wurtemberg, which lasted seven hours, no sound of the conflict was heard by Prince Schwartzenberg 13 miles up the river. A Prussian officer sent thither at noon first heard the cannonade at a distance of $4\frac{1}{2}$ miles from the field of battle. This happened on a day apparently resembling in point of mildness and serenity our 3rd of July. In the battle of Liegnitz, where Frederick the Great overthrew Laudon, the sound of the battle was unheard by Field-Marshal Daun, who was posted on a height $4\frac{1}{2}$ miles from the battle-field. DOVE himself recounts the fact of his having failed to catch a single shot of the battle of Katzbach at $4\frac{1}{2}$ miles distance, while he plainly heard the cannonade of Bautzen 80 miles away.

The stoppage of the sound in the foregoing cases DOVE referred, and doubtless correctly, to the non-homogeneous character of the air. He also notes the exceedingly interesting observation that in certain clear winter days, when the sun has already attained some power, the semaphore is difficult to decipher, the reason being that by the solar warmth upward currents of warm and downward currents of cold air (similar to those of HUMBOLDT on the plain of Antures) are established, and that such days are also unfavourable to the transmission of sound. In another passage, however, he seems to indorse the prevalent notion that the optical transparency of the air and its power to transmit sound go hand in hand; whereas in our experiments days of the highest optical transparency proved themselves acoustically most opaque.

But nothing of this description that I have read equals in point of interest the following account of the battle of Gain's Farm, for which I am indebted to the Rector of the University of Virginia.

"Lynchburgh, Virginia,
March 19th, 1874.

"SIR,—I have just read with great interest your lecture of January 16th, copied by LITTELL'S 'Living Age' from 'Nature,' on the acoustic transparency and opacity of the atmosphere. The remarkable facts you mention induce me to state to you a fact which I have occasionally mentioned, but always where I am not well known, with the apprehension that my veracity would be questioned. It made a strong impression on me at the time, but was an insoluble mystery until your discourse gave a possible solution.

"On the afternoon of June 28th, 1862, I rode in company with General G. W. RANDOLPH, then Secretary of War of the Confederate States, to PRICE'S house, about nine miles from Richmond; the evening before General LEE had begun his attack on M^C^CLELLAND's army, by crossing the Chickahominy about four miles above PRICE'S, and driving in the right wing of M^C^CLELLAND's army. The battle of Gain's Farm was fought the afternoon to which I refer. The valley of the Chickahominy is about one and a half mile wide from hill top to hill top. PRICE'S is on one hill top, that nearest to Richmond; Gain's Farm, just opposite, is on the other, reaching back in a plateau to Cold Harbour.

"Looking across the valley I saw a good deal of the battle, LEE's right resting in the valley, the Federal left wing the same. My line of vision was nearly in the line of the lines of battle. I saw the advance of the Confederates, their repulse two or three times, and in the grey of the evening the final retreat of the Federal forces.

"I distinctly saw the musket-fire of both lines, the smoke, individual discharges, the flash of the guns. I saw batteries of artillery on both sides come into action and fire rapidly. Several field-batteries on each side were plainly in sight. Many more were hid by the timber which bounded the range of vision.

"Yet looking for near two hours, from about 5 to 7 P.M. on a midsummer afternoon, at a battle in which at least 50,000 men were actually engaged, and doubtless at least 100 pieces of field-artillery, through an atmosphere optically as limpid as possible, *not a single sound of the battle* was audible to General RANDOLPH and myself. I remarked it to him at the time as astonishing.

"The cannonade of that very battle was distinctly heard at Amhurst Court-house, 100 miles west of Richmond, as I have been most credibly informed.

"Between me and the battle was the deep broad valley of the Chickahominy, partly a swamp, shaded from the declining sun by the hills and forest in the west (my side).

"Part of the valley on each side of the swamp was cleared; some in cultivation, some not. Here were conditions capable of providing several belts of air, varying in the amount of watery vapour, arranged like laminæ at right angles to the acoustic waves as they came from the battle-field to me. The direction of the valley is nearly due east and west. The part where the cannonade was heard 100 miles off was directly in the line of the valley, which, however, is a short one, less than 20 miles beyond the field.

"It occurred to me that this incident might interest you. I owe you thanks for the possible solution.

"Respectfully,

"Your obedient Servant,

"Professor JOHN TYNDALL." "R. G. H. KEAN."

I learn from a subsequent letter that during the battle the air was still.—J. T.

Partial Summaries of Observations in Chronological Order.

May 19. *Partial Summary of Day's Work.*—Maximum range of horns, with paddles stopped, from 3 to 4 miles; wind almost directly across the direction of sound. On the South Sand Head side nothing heard at the distance of a mile; wind opposed. On the Dover side a rapid and considerable fall of intensity; wind coincident. Whistles markedly inferior to horns. Axes of horns perpendicular to each other.

	Afloat.	Ashore.
Wind	E.N.E., 6 to 7	—
Barometer	29·9	—
Wet bulb	51°	—
Dry „	52°	—

May 20. *Partial Summary of Day's Work.*—Maximum range of horns, with paddles stopped, 5 to 6 miles; wind force 2, the larger component in favour of sound; sea smooth, and no noise on board. Guns heard by all observers at 9·7 miles; clearly the best. At 4 miles, though the horns lingered on further, they were barely heard with paddles stopped. The whistles had failed previously. The atmospheric conditions, to all appearance, highly favourable to the transmission of the sound.

	Afloat.		Ashore.
Wind	N.E., 2	....	—
Barometer	30·3	....	—
Wet bulb	—	....	—
Dry ,,	—	....	—

June 2. *Partial Summary.*—Maximum range of horns to leeward, paddles stopped, about 6 miles. At 3 miles in the axis E.S.E. all sounds were at first heard, and then became inaudible. At 2 miles in the axis three horns sounded together were inaudible. Sound fluctuated in consequence of high wind; in one instance heard out of axis, with paddles going, 3 miles.

	Afloat.		Ashore.
Wind	E.N.E., 7	....	—
Barometer	30	....	—
Wet bulb	—	....	—
Dry ,,	—	....	—

June 3. *Partial Summary.*—Maximum range in axis of horn, paddles stopped, over 9 miles; heard with paddles going full speed at $3\frac{3}{4}$ miles, with wind (force 3) almost opposed to sound. At the maximum distance (air still, sea smooth, and sun shining) a single small horn proved equal to two of them sounded together; a short wide horn proved slightly superior to a long narrow one. The howitzer, with 3-lb. charge, proved to be the best of the guns.

	Afloat.		Ashore.
Wind	S.S.W. to E.S.E.N.	....	E.N.E., 2
Barometer	29·9	....	29·6
Wet bulb	—	....	59°
Dry ,,	—	....	62°

June 10. *Partial Summary.*—Maximum range of 3 horns (1 large and 2 small) sounded together $8\frac{3}{4}$ miles; might have been heard further. Guns heard also at this distance, but not better than horns. Wind, force 4, almost directly across sound, but slightly against it. At 5 miles distance the large horn yielded a serviceable sound with paddles going. The whistles proved inferior to two small horns, and the latter inferior to the large single horn. Near edge of phonic area whistles better than horns. Between Foreland and Dover Pier sound of horns suddenly subsided. Signalled for guns; they also were unheard.

	Afloat.		Ashore.
Wind	S.W. and W.S.W., 5 to 3	....	—
Barometer	—	....	29·6
Wet bulb	—	....	56°
Dry ,,	—	....	58°

June 11. *Partial Summary.*—This day was occupied in examining the decay of the sound near the edge of the phonic area at both sides of the Foreland. At the pier, and a quarter of a mile from it, no sound heard. Wind, force 2, almost dead against sound. On the South Sand Head side decay also very striking, and more striking at 2 miles than at $3\frac{3}{4}$ miles: wind here, force 2, in favour of sound. The wind unable to atone for the acoustic opacity of the day. As before, near edge of phonic area the whistles surpassed the horns.

	Afloat.		Ashore.
Wind	S.W. and W.S.W., 2 to 3	....	—
Barometer	29·7	....	29·5
Wet bulb	—	....	55°
Dry ,,	—	....	56°

June 25. *Partial Summary.*—Maximum range of horns in axis $6\frac{1}{2}$ miles. Sounds lost at this distance, but again revived to loudness. A second trial caused the sounds to vanish at 6·4 miles; wind in favour of sound. The 18-pounder inferior to horns at $5\frac{1}{2}$ miles on axis.

	Afloat.		Ashore.
Wind	W.N.W., W. by N. to N.W., 4	....	—
Barometer	—	....	29·7
Wet bulb	59°	....	57°
Dry „	$62\frac{1}{2}$°	....	63°

June 26. *Partial Summary.*—Maximum range for whistle and horns $9\frac{1}{4}$ miles, with paddles quiet; the horns could have been heard further, though the wind, with a force of 4, was against the sound. On the 25th the maximum range, with the wind favourable, was 6·4 miles. Something, therefore, besides the wind must affect the sound-range. Sound heard at 5·4 miles through paddle-noises and slop of the sea.

	Afloat.		Ashore.
Wind	S.W.	....	W.N.W., then W.S.W.
Barometer	30·3	....	30
Wet bulb	60°	....	62°
Dry „	62°	....	66°

July 1. *Partial Summary.*—Maximum range Varne light-ship, $12\frac{3}{4}$ miles; maximum observed on board the 'Irené' $10\frac{1}{2}$ miles. Heard through paddle-noises $6\frac{3}{4}$ miles. Afloat, wind almost dead against sound; on shore across it. Thick haze, but acoustically a very transparent day. Horn rotated, and strengths of its various blasts expressed numerically; direct or axial blast strongest. Proved that subsidence of sound at edge of phonic area is not due to deviation from axis, because it occurs when axis is directed along the edge. The American whistle did not manifest any remarkable power: this day was the first occasion of its trial.

	Afloat.		Ashore.
Wind	S.S.W. to S.W., 2	......	N.W., 3, to W.S.W., 2
Barometer	30	......	29·8
Wet bulb	61° to 60°	......	62°
Dry „	67° to 62°	......	67°

July 2. *Partial Summary.*—A very different day, acoustically, from yesterday. Maximum range in axis only 4 miles; wind oblique and against sound; sea noisy. Acoustic opacity of atmosphere augmented from the morning onwards. Near end of Dover Pier, to windward, sounds not heard; on the other side of Foreland, to leeward, sounds well heard.

	Afloat.		Ashore.
Wind	W.S.W. and S.W., 5	....	—
Barometer	30·1	....	29·8
Wet bulb	58°	....	60°
Dry „	61°	....	62°

July 3. *Partial Summary.*—Maximum range at 2 P.M. under 3 miles: cannon scarcely heard at 2 miles. The obscuration of the sun by a cloud diminished the aërial opacity; the sinking of the sun diminished it still more, and caused sound to reach men in an anchored boat, where half an hour previously nothing could be heard. Range subsequently extended beyond the Varne buoy and to the Varne light-vessel. Day singularly calm and optically clear: dead calm, indeed, afloat.

	Afloat.		Ashore.
Wind	Calm	....	S.S.E., 2
Barometer	30	....	29·7
Wet bulb	68° to 61°	....	63° to 59°
Dry „	71° to 61°	....	69° to 63°

July 4. *Partial Summary.*—Maximum range probably from 4 to 5 miles: horn heard through paddle-noises, not the whistle. Gun-sounds superior to any thing on this day. Sounds unheard at $5\frac{1}{2}$ miles.

	Afloat.		Ashore.
Wind	W.S.W., 7		—
Barometer	29·9		29·5
Wet bulb	$61\frac{1}{2}$°		61°
Dry "	64°		64°

October 8. *Partial Summary.*—Maximum range over 9 miles; howitzer loud, syren clear, horn feeble. No wind at the time of maximum, but following closely upon heavy squall of rain and hail. Previously, at $5\frac{1}{2}$ miles the sounds had been much more feeble.

	Afloat.		Ashore.
Wind	Calm to W.S.W., 3, to N. by W., 2		W.S.W., 2, to N.W., 3
Barometer	29·6		29·4
Wet bulb	52° to 48°		50° to 45°
Dry "	55° to 48°		54° to 46°

October 9. *Partial Summary.*—Maximum range $7\frac{1}{2}$ miles; syren faint but distinct. Syren better than gun or horn with wind across; gun better than syren or horn with wind directly favourable to sound. Good and serviceable sound from syren heard at 3 miles distance to windward, 'Galatea' steaming at full speed.

	Afloat.		Ashore.
Wind	W.S.W., 3 to 6		W.S.W., 5 to 6
Barometer	29·9		29·6
Wet bulb	54°		49°
Dry "	58°		55°

October 10. *Partial Summary.*—The syren maintained its superiority during land-observations: deep in the sound-shadow both its direct sound and long-drawn echoes were heard when the horn and its echoes were inaudible. A strong wind was blowing against the sound at this time.

October 11. *Partial Summary.*—In the land-observations of this day the syren proved itself superior to the gun against a strong wind: indeed at 550 yards dead to windward of the station the smoke of the gun was seen, but no sound heard, whilst at the same time the syren was piercingly intense; to leeward the gun-sound travelled a very much greater distance. The shortness of the gun-sound is not favourable for the purposes of signalling. Moderate gale from S.W. all day.

October 13. *Partial Summary.*—$2\frac{1}{2}$ miles E. of station, syren superior to horn, Canadian whistle, or gun. Same distance W. of station, gun louder than any thing; then syren. Canadian whistle equal to horns on both sides. In the axis horn better than whistle. All sounds heard during descent of very heavy rain. Locality of station discovered, when hidden in thick mist, by sound alone.

	Afloat.		Ashore.
Wind	N.W. by W., 2 to 4		N.N.W., 3
Barometer	29·7		29·3
Wet bulb	57° to 53°		52° to 49°
Dry "	58° to 54°		55° to 50°

October 14. *Partial Summary.*—Maximum range 10 miles; in the morning at the Varne buoy, the distance being $7\frac{3}{4}$ miles, all sounds well heard. With a changed atmosphere at the same spot, four hours later in the day, the syren was feeble and the gun and horns not heard. It was not the wind which caused this difference, for it had then the same direction and force as in the morning. At 5 miles in the axis the sounds were all much more feeble than at $7\frac{3}{4}$ miles at the Varne buoy, which was out of the axis, in the morning. At 4 miles to leeward the syren was strong, the gun loud, horns and Canadian whistle plainly heard.

	Afloat.		Ashore.
Wind........	N.N.W. and W.N.W., 2 to 3	......	N.W., 2
Barometer....	30·00	......	29·6
Wet bulb....	54° to 57°	......	55° to 48°
Dry „	57° to 61°	......	59° to 52°

October 15. *Partial Summary.*—Inspected Dungeness rotating fog-horn. Maximum range, with horn pointed on us, 3·9 miles, then barely audible: lost at 4 miles. Report of gun much louder than direct sound of horn at 3·9 miles. In the other medial line range of horn still less. Aërial echoes of 4 seconds duration returned in every case from the direction in which the horn was pointed.

	Afloat.		Ashore.
Wind	nil	....	—
Barometer	30·00, falling	....	—
Wet bulb................	55°	....	—
Dry „	59°	....	—

October 16. *Partial Summary.*—Maximum range in axis 5 miles: syren faintly heard; gun seen but not heard. With paddles going syren heard at $3\frac{1}{2}$ miles in axis; gun seen but not heard at $2\frac{1}{2}$ miles. Round arc of 2 miles radius from South Foreland the results were as follows:—Deep in sound-shadow on Dover side syren much enfeebled; Canadian whistle at times equal to it; gun yielded only a thud. In sound-shadow on South Sand Head side the syren was again much enfeebled, and at times surpassed by the Canadian whistle: here the gun gave a loud report, there being a component of wind in favour of the sound. On clearing the shadows of the intervening projecting cliffs on either side all the sounds were much louder; and on nearing the axis of the syren its sound rose to an extraordinary intensity, surpassing the loud report of the gun.

The Canadian whistle has shown itself much superior to the other whistles.

	Afloat.		Ashore.
Wind................	W.S.W., 2 to 3	....	S.W., 3
Barometer...........	30·2	....	29·9
Wet bulb	60° to 56°	....	55° to 48°
Dry „	64° to 60°	....	60° to 51°

October 17. *Partial Summary.*—Four horns tried against syren: proved inferior to it. A day of great acoustic transparency. Maximum range with vessel stopped, gun $16\frac{1}{2}$ miles, dull report; syren and horns heard occasionally at 15 miles in axis. Early in the day, with paddles going, syren heard at 7 miles in axis, while gun and horns were inaudible at $5\frac{1}{2}$ miles. In sound-shadow, Dover side, syren proved itself superior to gun and horns. The limit of the sound-shadow was to-day very sharply defind. At the base of the South Foreland cliff the aërial echoes of the syren-sound lasted from 14 to 15 seconds: the echoes were observed to strike in upon the direct sound one second after commencement of the actual blast.

	Afloat.		Ashore.
Wind................	calm and N.E., 1	....	S.E., 1
Barometer...........	30·2	....	29·9
Wet bulb	54° to 61°	....	54° to 50°
Dry „	57° to 66°	....	60° to 54°

October 18. *Partial Summary.*—Experiments on pitch and pressure of syren. At 2 miles 2400 probably better than 1500 revolutions per minute. The greater pressure yields the harder and firmer sound. Reports heard in the morning proved to come from rifle practice on Kingsdown beach, $5\frac{1}{2}$ miles off, or twice the distance at which cannons were heard on July 3. Dead to leeward, about 4 miles, missed hearing a gun through not attending. Gun requires a prepared attention to hear it.

	Afloat.		Ashore.
Wind	W., 2		W.S.W., 3
Barometer	30·1		29·8
Wet bulb	54° to 56°		54°
Dry „	56° to 59°		59°

October 20. *Partial Summary.*—A day of atmospheric variation and consequent variability of sound-range; strong wind, high sea, and much local noise. At 5·7 miles to leeward syren more distinct than gun; at some shorter distances gun-sound quenched by local noises, but not so with the syren-sound. Across the wind the syren was heard through paddle-, sea-, and wind-noises at 5 miles; horns (two small ones) weak at $3\frac{1}{2}$ and inaudible at 4 miles. Gun-report not picked up by some ears so well as the hard and sustained sound of the syren; horn a soft musical sound, inferior to explosive blast of the syren.

	Afloat.		Ashore.
Wind	W. by S. to N.N.W., 6 to 8		N.N.W., 5 to 7
Barometer	29·9		29·6
Wet bulb	55° to 49°		55° to 42°
Dry „	55° to 51°		57° to 45°

October 21. *Partial Summary.*—Strong wind, high sea. At $6\frac{1}{2}$ miles in the axis, paddles going, wind across, syren heard clearly; gun seen, but not heard: horns lost after 4 miles. At $4\frac{3}{4}$ miles in axis vessel stopped in the midst of heavy rain and high wind; gun, horns, and whistles heard, but syren burst out with sudden power, overmastering them all.

	Afloat.		Ashore.
Wind	W.N.W. to W., 5 to 7		W., 5
Barometer	29·8, falling		29·6, falling
Wet bulb	48° to 52°		46°
Dry „	49° to 52°		48°

October 22. *Partial Summary.*—Land-observations only. At the Cornhill Coastguard Station, distant 1 mile, with a very strong wind blowing directly against the sound, the syren and horns (the latter pointed towards us) were heard distinctly, while the smoke of the gun was seen, but the sound was not heard. Sheltered from the wind the gun was heard distinctly. At a greater distance, sheltered from the wind by a furze bush, the syren and horns were heard, but not the gun. Gun-sound liable to be obliterated by a passing puff of wind. To leeward, on the cliff beyond St. Margaret's Bay, the gun-report was very loud, the syren and horn-sounds being also very powerful.

	Afloat.		Ashore.
Wind	—		W.S.W., 5
Barometer	—		29·1
Wet bulb	—		56° to 49°
Dry „	—		57° to 52°

October 23. *Partial Summary.*—Land-observations only. Strong wind, at times increasing to a gale. Mr. AYRES, 600 paces to windward, heard syren distinct, horn indistinct, gun not all. Syren also heard distinctly through thunderstorm; gun and horns inaudible. At $1\frac{1}{4}$ mile in same direction syren always heard, generally distinct and strong; gun and horns only heard 3 times. Mr. DOUGLASS, to leeward, carried syren-sound to $7\frac{1}{3}$ miles, having lost the gun at $6\frac{3}{4}$. During thunderstorm and heavy rain, sounds were heard plainly at $2\frac{1}{2}$ miles which had previously been inaudible. In rear of instruments effective range of sounds about a mile, syren predominating.

	Afloat.		Ashore.
Wind	—		W. and W.S.W., 6 to 8
Barometer	—		28·6, rising
Wet bulb	—		50°
Dry „	—		52°

October 24. *Partial Summary.*—Observations by Mr. DOUGLASS in 'Palmerston' steam-tug. Wind light, and sea quiet. Maximum range, syren $7\frac{3}{4}$ miles, feeble sounds, distinct at 5 miles. Gun unheard at 5 miles, low thud at 3·9, but unheard at 3 miles to windward. All sounds heard through rain and squall 3 miles distant. In sound-shadow, South Sand Head side, distant from station 3 miles, syren only heard.

	Afloat.		Ashore.
Wind	E.S.E., 3	....	S.E. and E.S.E., 3 to 5
Barometer	—	....	28·9
Wet bulb	—	....	45° to 43°
Dry „	—	....	49° to 43°

October 27. *Partial Summary.*—Wind strong, sea rough. At sea in axis syren heard at 6 miles; nothing else. Heard also with paddles going up to 5 miles. Gun feeble at 4 miles, unheard at 5; horns barely audible at 4 miles. Wind across, force 5. Nearly dead to windward $1\frac{3}{4}$ mile, syren distinct through paddle-noises; horns just audible; gun seen but not heard. To leeward syren good at 5 miles, gun fair, horns feeble. On land to leeward all heard at 6 miles. Sounds very loud in Dover all day.

	Afloat.		Ashore.
Wind..............	E.N.E., 6	....	N.N.E., 5
Barometer..........	—	....	30·00
Wet bulb	—	....	44° to 41°
Dry „	—	....	47° to 44°

October 28. *Partial Summary.*—Thick haze round horizon, South Foreland invisible; zenith blue; sun shining. Maximum range $7\frac{1}{2}$ miles in axial line; gun-report fair, syren-sound also fair; 2400 revolutions rather better than 1500. At 6 miles, syren with 2400 revolutions distinctly superior to gun; subsequently, vessel having drifted out of axis and the atmosphere having changed, neither gun nor syren heard at 6 miles, though nearly dead to leeward. Nothing heard all day on board South Sand Head light-ship; but, through action of wind, sound loud in Dover, and heard in the middle of Folkestone.

	Afloat.		Ashore.
Wind	N. by E. to N., 3	....	N.N.W. to N., 3
Barometer	30·5, falling	....	30·1, falling
Wet bulb	48°	....	45° to 39°
Dry „	51°	....	49° to 40°

October 29. *Partial Summary.*—Afloat, in axial line, high and low notes of syren faint at 7 miles; high note rather better than low. Gun barely heard at 5 miles. Subsequently, gun was seen and not heard at various distances down to $2\frac{1}{2}$ miles. Wind across, force 3. At $3\frac{1}{2}$ miles dead to windward the syren was faintly heard; gun not heard at $2\frac{3}{4}$ miles. Echoes observed to come strongest from windward. On land, to windward, Mr. DOUGLASS carried sounds to between 2 and $2\frac{1}{2}$ miles; to leeward Mr. EDWARDS heard the sounds at 7 miles; and Mr. AYRES, in rear of instruments, carried the sounds inland for 5 miles.

	Afloat.		Ashore.
Wind	E.S.E. to E.N.E., 3	....	E. to E.N.E., 4
Barometer	30·3	....	29·9, falling
Wet bulb	48°	....	42° to 38°
Dry „	52°	....	48° to 44°

October 30. *Partial Summary.*—No wind. Nearly at right angles to their axes, gun and syren heard at $11\frac{1}{2}$ miles: horns not heard. At $8\frac{1}{2}$ miles syren-sound efficient, with paddles going, strikingly superior to gun. Subsequently in axis, with a rising wind, no sounds heard at $6\frac{1}{2}$ miles; horns lost at a little over 5 miles; at the same time gun very feeble. At South Sand Head, distance $3\frac{3}{4}$ miles, wind across, force 5, syren very feeble; gun and horns not heard. On land, wind across, syren only heard 3 miles N.E. of South Foreland; but on Folkestone Pier, 8 miles on the other side, syren heard plainly. Guns and horns not heard beyond Folkestone Hill.

	Afloat.		Ashore.
Wind	Calm to N.N.W., 5	....	N.W., 2 to 4
Barometer	—	....	29·5
Wet bulb	—	....	43° to 40°
Dry „	—	....	45° to 42°

October 31. *Partial Summary.*—Sea rough, wind and rain. Nearly at right angles to its axis, syren exceedingly faint at $3\frac{3}{4}$ miles; no sound of gun or horns. In axis, syren well heard through paddle- and other noises up to $2\frac{3}{4}$ miles. In a violent rain-squall, wind force 8, more than 2 miles from station, forcible sound heard from syren; other signals not heard: with less wind, syren heard off end of Admiralty Pier, directly to windward; gun-sounds quenched; horn-sounds very faint. Atmosphere exceedingly opaque to sound.

	Afloat.		Ashore.
Wind	S.W. by S. to W., 4 to 8	....	W.S.W., 6 to 4
Barometer	29·6	....	29·6
Wet bulb	52°	....	47°
Dry „	54°	....	50°

November 1. *Partial Summary.*—Land-observations by Mr. DOUGLASS. On ramparts of Dover Castle, 2 miles from South Foreland, wind obliquely against sound, syren distinctly more audible than horn, though the latter was pointed towards the castle; horn feeble; gun not heard. On the other side, with wind obliquely favourable to the sound, at 6·9 miles distance, the syren and horn (the latter now pointed eastward) were barely audible; the gun was not heard. Aërial echoes, 11 seconds in duration, at South Foreland.

	Afloat.		Ashore.
Wind	—	....	W.S.W., 5 to 3
Barometer	—	....	28·9
Wet bulb	—	....	49° to 46°
Dry „	—	....	52° to 50°

November 21. *Partial Summary.*—The gun was first fired along the line between the observers and the Foreland, and then at right angles to this line. The report in the former case was sensibly, though not much, louder than in the latter. The syren was then blown in the same manner, first with its axis directed upon us, and then in the perpendicular direction. The fall of intensity in passing from the one position to the other was far more considerable than in the case of the gun. Striking subsidence of sound near the boundary of acoustic shadow. Guns fired to leeward produced louder and longer echoes than when fired to windward.

	Afloat.		Ashore.
Wind	S.S.W. to W.S.W., 2 to 5	....	S.W., 3
Barometer	29·9, falling	....	29·5, falling
Wet bulb........	41° to 44°	....	40°
Dry „	44° to 46°	....	42°

November 22. *Partial Summary.*—Yesterday's experiments were repeated and amplified; result substantially the same.

	Afloat.		Ashore.
Wind	W.N.W. to N.W., 7	....	N.N.W., 7
Barometer	29·5	....	29·1, rising
Wet bulb	50°	....	47°
Dry „	54°	....	51°

November 24. *Partial Summary.*—Sound in rear of syren, to leeward, stronger than in front; stronger also at $2\frac{1}{2}$ miles than at 1 mile. A vast augmentation of the sound when syren was turned to leeward. Whistles tested: Canadian and 8-inch whistle proved to be the best. The syren, with disks alone, unaided by trumpet, proved to be about equal to the best whistles.

	Afloat.		Ashore.
Wind	W., 2 to 3	....	W.S.W., 3
Barometer	29·9	....	29·6
Wet bulb	47° to 52°	....	46° to 49°
Dry „	48° to 52°	....	47° to 50°

November 25. *Partial Summary.*—Acoustic opacity nearly equal to that of July 3. At 2·8 miles, with all quiet, sounds exceedingly feeble; no guns heard. Gun yielded only a faint crack at 2½ miles. Day then very calm. Change of wind brought with it augmentation of sound. The Canadian whistle compared with the horn to-day, and found superior to it. Syren for a time not in action. Eight-inch whistle feeble to-day. Syren sounded afterwards both level and depressed; no sensible difference.

	Afloat.		Ashore.
Wind	Calm and E.N.E., 1	....	S. and S.E., 1
Barometer	30·2	....	29·8
Wet bulb	56° to 51°	....	51° to 47°
Dry „	52°	....	53° to 48°

The barometer and thermometer observations were made afloat by Mr. EDWARDS; ashore by Mr. AYRES.

Table of Ranges of HOLMES'S *Horns.*

May 19th	....	3½ miles.		
„ 20th	....	4 to 5½	„	
June 2nd	....	6	„	
„ 3rd	....	9	„	
„ 10th	....	8¾	„	
„ 25th	....	6½	„	
„ 26th	....	9¼	„	
July 1st	....	12¾	„	
„ 2nd	....	4	„	
„ 3rd	....	2½	„	and 12¾ miles.
„ 4th	....	3¾	„	

Syren and Horns.

			Syren.		Horns.	
October	8th	....	10 miles	....	9 miles.	
„	9th	....	7½ „	....	4 „	
„	14th	....	10 „	....	10 „	and 7½ miles.
„	15th	....	no syren	....	3·9 „	(Daboll).
„	16th	....	5 miles	....	no horn.	
„	17th	....	15 „	....	15 miles	(4 horns).
„	20th	....	6½ „	....	3¾ „	
„	21st	....	6½ „	....	4 „	
„	23rd	....	7⅓ „	....	6 „	(on land).
„	24th	....	7¾ „	....	3½ „	
„	27th	....	6 „	....	4¼ „	
„	28th	....	7½ „	....	no horn.	
„	29th	....	7 „	....	„	
„	30th	....	11½ „	....	8½ miles.	
„	31st	....	3¾ „	....	2½ „	bearing off Varne.
November	1st	....	6·9 „	....	——	(on land).
„	25th	....	4 „	....	——	

Range of syren to range of horn as 7 : 5 nearly.

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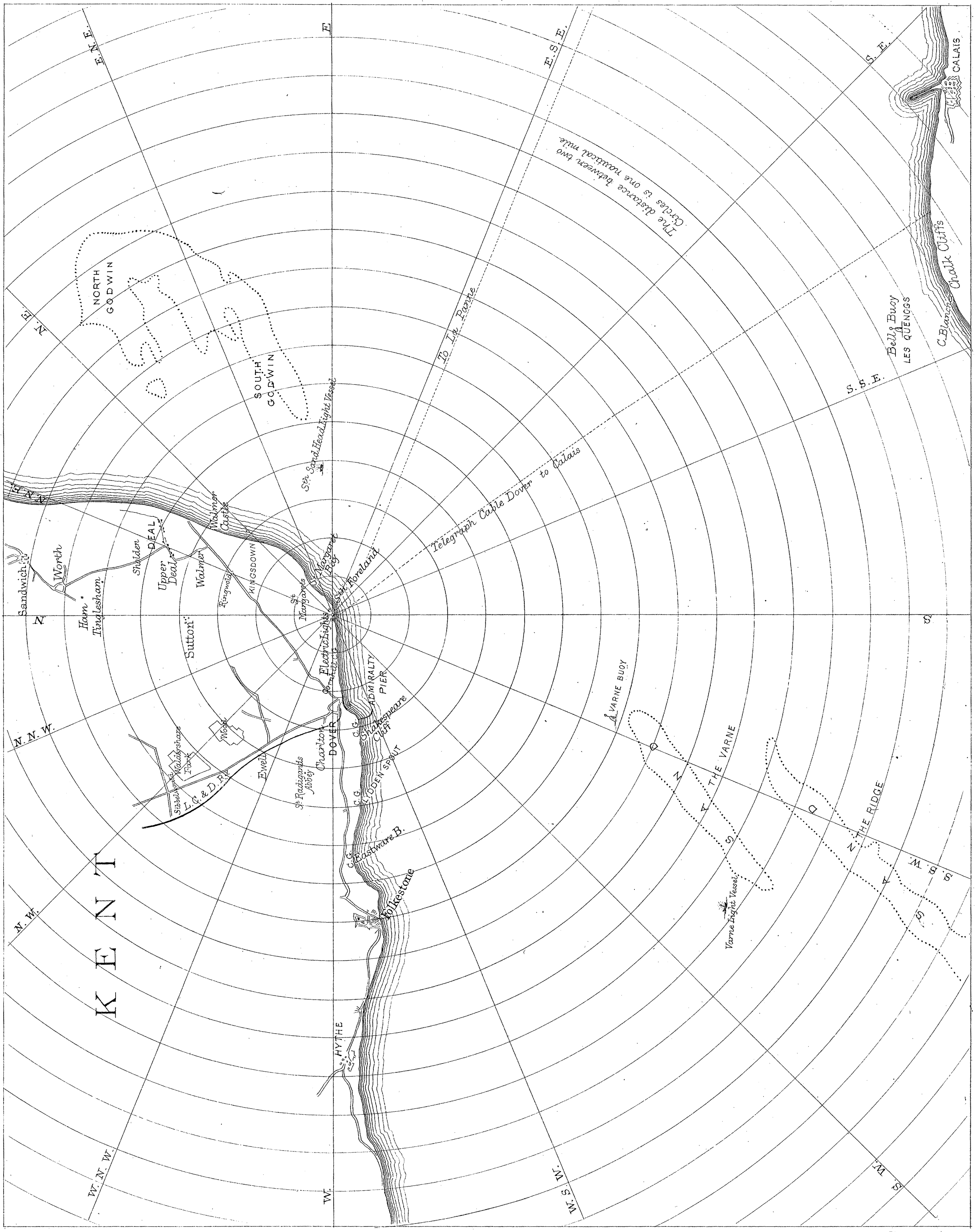


W. West & Co. lith.

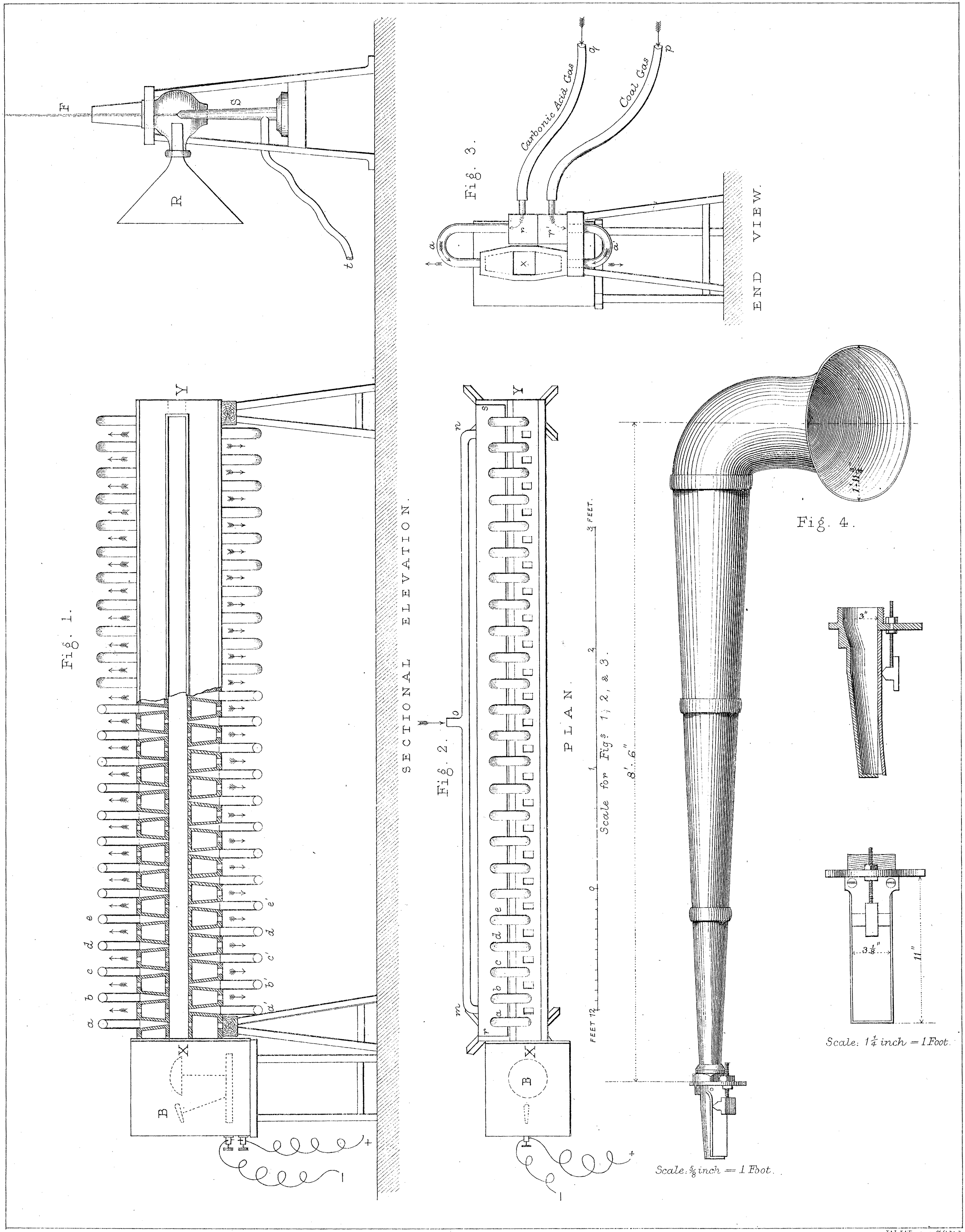
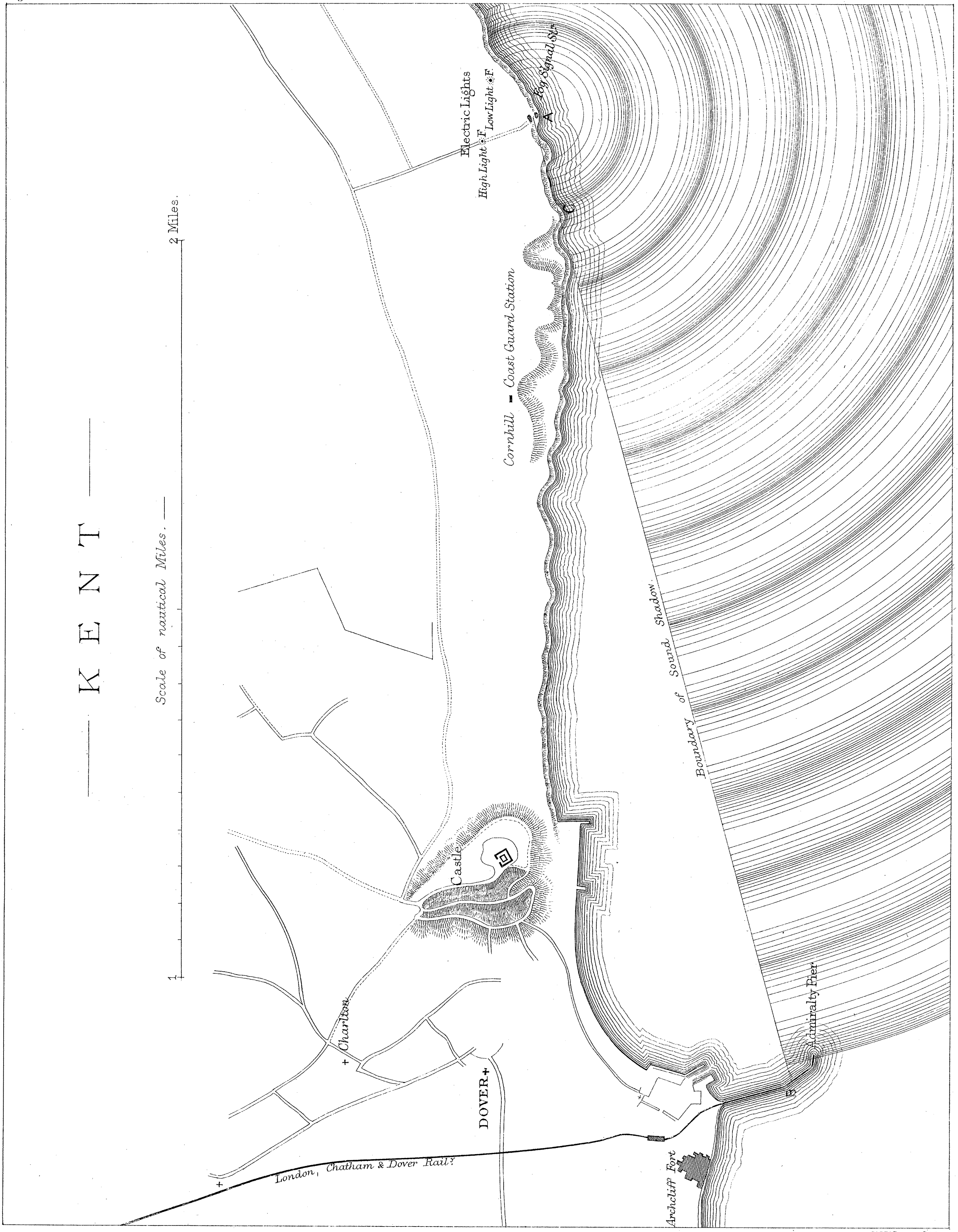


Fig. 1.
SECTIONAL ELEVATION.
Fig. 2.
PLAN.
Fig. 3.
END VIEW.
Carbonic Acid Gas
Coal Gas
Fig. 4.
Scale for Figs 1, 2, & 3.
FEET
8'. 6"
3"
3 1/8"
11"
Scale: 5/8 inch = 1 Foot.
Scale: 1 1/4 inch = 1 Foot.



W. West & Co. lith.