THE ACOUSTIC TRANSPARENCY AND OPACITY OF THE ATMOSPHERE *

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

A disastrous loss of life and property is the consequence. During the last ten years, for example, the number of total wrecks on the coasts of the United Kingdom, which were reported to have been caused by fog and thick weather, amounted, I am informed, to 273 vessels.

Of late years various efforts have been made, both on our own coasts and on the American seaboard, where trade is more eager and fogs more frequent than they are here, to furnish warning and guidance to ships by means of sound signals of great power established along the coast. Regarding the performance of such signals, the most conflicting evidence exists; and no investigation has been hitherto instituted sufficiently exhaustive to remove the uncertainty.

The problem has occupied for some time the attention of the Elder Brethren of the Trinity House; and soon after my return from America they requested me, as their official adviser in scientific matters, to superintend an investigation of the entire subject. They had appointed a committee under whose auspices two stations had been established at the South Foreland. I entered upon the inquiry with such ardour as I could derive from a sense of duty, rather than from the pleasure of hope, for I knew it would be long and difficult, and that I was at the mercy of a medium, the earth's atmosphere, which could not be put into the witness-box and cross-examined scientifically. The experimenter can usually impose his own conditions upon Nature, and force her to reply. In the present case we were forced to accept the conditions which Nature imposed.

Nevertheless, if the student only holds on faithfully to any natural problem, intending his mind upon it, and not falling into hasty despair, he is sure to be rewarded in the end; and after a time results, important not only in a practical but in a purely scientific point of view, appeared to grow out of the investigation. I mentioned this to the Deputy Master of the Trinity House, saying that I thought such results might, without impropriety, be communicated to the Royal Society and the Royal Institution. His response was prompt and cordial, and he was seconded by his colleagues in this response. They gave not only the requested permission (which on various pleas they might have withheld), but they have aided me in every way in the preparation of this discourse.

I would add that the Elder Brethren themselves have had a large share in the executive portion of this investigation, and whatever success has attended the inquiry is in a great measure due to the cheerful promptness and thoroughness with which my wishes and suggestions were carried out by the gentlemen with whom I had the honour to act. It is not necessary to mention names when all have been so sympathetic and so helpful, but I should like to refer to a few gentlemen on the working staff of the Trinity House, who have aided me with all assiduity and all zeal. They are the able Trinity House engineer, Mr. Douglass, his assistant engineer, Mr. Ayres, and Mr. Price Edwards, the private secretary of the Deputy Master of the Trinity House.

On Monday, May 19, the experiments began. The instruments employed had been previously mounted at the top and bottom of the South Foreland Cliff. They were two brass trumpets, or horns, 11 ft. 2 in. long, 2 in. in diameter at the mouth-piece, opening out at the other end to a diameter of 22 in. They were provided with vibrating steel reeds, 9 in. long, 2 in. wide, and ¼ in. thick, and were sounded by air of 18 lbs. pressure. They were mounted vertically on the reservoir of compressed air; but within about 2 ft. of their extremities they were bent at a right angle, so as to present their mouths to the sea. These horns were constructed by Mr. Holmes. There were also two whistles shaped like those in use on locomotives, one 6 in. in diameter, sounded by air of 18 lbs. pressure; the other constructed by Mr. Baily of Manchester, 12 in. in diameter and sounded by steam of 64 lbs. pressure.

We embarked on the steamer *Irene*, and placed ourselves abreast of the signal-station, halting at a distance of half a mile from it. The wind was strong, the sea rough. The superiority of the trumpets to the whistles was very marked, and I may say continued marked throughout. Their sound was exceedingly fine and powerful. At 1 mile's distance their sound was clear and strong; at 2 miles they were heard distinctly, though not loudly. The whistles were also heard, but as fog-signals they had become useless. At 3 miles the horns became also useless. It required great attention to hear them distinctly. At a distance of 4 miles, with the paddles stopped, we listened long and attentively, but heard nothing.

On May 20, at 3 miles' distance, the steam whistle was not at all heard, the horns but faintly. At 4 miles' distance, the air being very light, the sea calm, and the circumstances generally to all appearances highly favourable, we halted and listened. The horns were so heard as to render it unmistakeable that a sound was there. At 4·8 miles the sounds were faintly heard; at 5 miles an occasional murmur reached us. At 6 miles the faint hum of a horn was wafted to us at intervals. A little farther out, though local noises were absent, and though we listened with stretched attention, we heard nothing.

This position, clearly beyond the range of whistles and trumpets, was chosen with the view of making a decisive comparative experiment between horns and guns as instruments for fog-signalling. Through the courtesy of General Sir A. Horsford we were enabled to carry out this comparison. 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 farther 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 8½ miles, where the report of a second gun was well heard. At 10 miles the report of the gun was heard by some and not by others. At 9·7 miles a fourth report was heard by all observers.

There was nothing, far as I am aware of, in our knowledge of the transmission of sound through the atmosphere, to invalidate the founding upon these experiments of the general conclusion that, as a fog-signal, the gun possessed a clear mastery over the horns. No observation, to my knowledge, had ever been made to show that a sound once predominant would not always be predominant; or that the atmosphere on different days would show preferences to different sounds. A complete reversal of the foregoing conclusion was therefore not to be anticipated; still, on many subsequent occasions, it was completely reversed.

On June 2 the maximum range, at first only 3 miles, afterwards ran up to about 6 miles.

Optically June 3 was not at all a promising day; the clouds were dark and threatening; and the air filled with a faint haze, nevertheless the horns were fairly audible at 9 miles. An exceedingly heavy rain-shower approached us at a galloping speed.

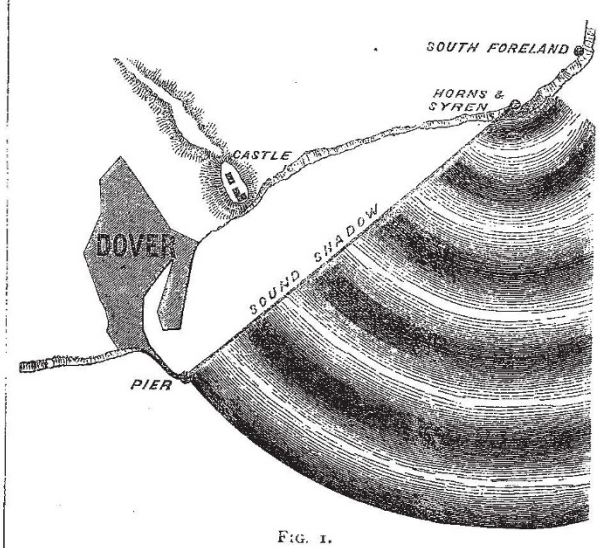

FIG. 1.

The sounds were not sensibly impaired during the continuance of the rain. This state of the atmosphere, according to hitherto

* Royal Institution, Friday evening Discourse by Prof. Tyndall, D.C.L. LL.D., F.R.S. Jan. 16.

expressed opinions, should have deadened the sound. It rather aided the sound, and this added to my perplexity.

On June 10 the maximum range was 9 miles. An extraordinary sinking of the sound was, however, noticed on the Dover side of the Foreland. At a mile's distance from the station the sounds rapidly fell. Surprised at the suddenness of the effect, and thinking it might be due to some peculiarity of the horns, at 2 miles' distance I signalled for the guns. With a 3 lb. charge not one of them was heard.

On June 11 we steamed towards the South Sound Head lightship. At the distance of 2¾ miles, and even at 2 miles and less from the station, the sounds were not so strong as at 3¾ miles. We steamed abreast of the station and on to the line joining the South Foreland to the end of the Admiralty Pier. At three-quarters of a mile from the station the sound fell, and a little farther on was scarcely audible. This weakening of the sound between the pier and the Foreland was invariable. This needs a word of explanation. The fall of the sound is not caused directly by an acoustic shadow, for it occurs when the instruments are in view, but the limit of an acoustic shadow is close at hand. A little within the line joining the Foreland and the pier end, the instruments are cut off by a projection of the cliff near the station; all the sea space between this limit and the cliff under Dover Castle is in the shadow. Into this, however, the direct waves diverge, and lose intensity by their divergence, the portion of the wave nearest the shadow suffering most. To this must be added the effect of interference.

On June 25 the range was 5½ miles. On June 26 the range was 10 miles. The former day the wind was in the direction of the sound; on the latter the wind was opposed. Plainly there must be something besides the wind which determines the sound-range. This something was now the object of search.

Is it the clearness of the atmosphere? All previous writers have extolled a clear atmosphere as best for sound; but on July 18 we steamed out to a distance of 10 miles and heard sounds, the white cliffs of the Foreland being at the same time entirely hidden in thick haze. Nay, more: we spoke the *Triton* tender on its way from the *Varne* lightship, and took the master of the *Varne* on board. He reported that the sounds had been heard at the lightship, though it is 12¾ miles from the Foreland. It was, moreover, dead to windward of the Foreland, so that both haze and wind were then in opposition; still the sound ranged at least twice as far as it had done on days when neither haze nor wind was there to interfere with the sound.

On July 2, a sudden acoustic darkness, if I may use the term, settled upon the atmosphere. The range was only 4 miles. The magnitude of the fluctuations, from 3½ to 12¾ miles, observed up to this date, was striking: but I was unable to fix upon any meteorological element that could be held accountable for them. The wind, the clearness of the air, the barometer, the thermometer, the hygrometer, gave me no help. All was perplexity. I longed for light, but saw little prospect of obtaining it.

July 3 was a lovely morning: the sky was of a stainless blue, the air calm, and the sea smooth. I thought we should be able to hear a long way off. We steamed beyond the pier end and listened. The steam clouds were there, showing the whistles to be active; the smoke puffs were there, attesting the activity of the guns. Nothing was heard. We went nearer; but at two miles horns and whistles and guns were equally inaudible. This however being near the limit of the sound shadow, I thought that might have something to do with the effect, so we steamed right in front of the station, and halted at 3¾ miles from it. Not a ripple nor a breath of air disturbed the stillness on board, but we heard nothing. There were the steam-puffs from the whistles, and we knew that between every two puffs the horn sounds were embraced, but we heard nothing. We signalled for the guns: there were the smoke puffs apparently close at hand, but not the slightest sound. It was mere dumb show on the Foreland. We steamed in to 3 miles, halted, and listened with all attention. Neither the horns nor the whistles sent us the slightest hint of a sound. The guns were again signalled for; five of them were fired, some elevated, some fired point blank at us. Not one of them was heard. We steamed in to two miles, and had the guns again fired: the howitzer and mortar with 3 lb. charges yielded the faintest thud; and the 18-pounder was quite unheard.

In the presence of these facts I stood amazed and confounded, for it had been assumed and affirmed by distinguished men who had given special attention to this subject, that a clear, calm atmosphere was the best vehicle of sound: optical clearness and acoustic clearness were supposed to go hand in hand: indeed, it had been proposed to make the one a measure of the other. But here was a day perfectly optically clear, proving itself to be a day of acoustic darkness almost impenetrable. I was driven slowly to the conclusion that all I had read upon this subject was wrong, and that for 165 years, namely since 1708, when Dr. Derham published his celebrated paper on this subject, succeeding generations of scientific men had gone on repeating the same errors. This knowledge, however, did not help me much. The problem was still there challenging solution.

I ventured, two or three years ago, to say something regarding the function of the Imagination in Science, and notwithstanding the care that I took to define and illustrate its real province, many persons, amongst whom were one or two able men, deemed me loose and illogical; in fact, merely poetic, when I referred to the imagination. The history of science, however, numbers many men of strong poetic temperament, who, in the presence of a scientific problem, became as cold and clear as the light of stars. Look at these two pieces of polished steel. Have you a sense, or the rudiment of a sense, to distinguish the inner condition of the one from that of the other? And yet they differ materially, for one is a magnet, the other not. What enabled that noble philosopher, and pure and elevated character, Ampére, to surround the atoms of such a magnet with channels in which electric currents ceaselessly run, and to deduce from these pictured currents all the phenomena of ordinary magnetism? What enabled Faraday to visualise his lines of force, to follow them through magnets and through space until his mental picture became a guide to discoveries which have rendered this place immortal? What but imagination? I have reason to know but too well the fantastic, and even scandalous use that is made of the faculty when it is divorced from the disciplined understanding and handed over to the undisciplined passions and emotions. But this is not the scientific use of the imagination.

And now to return. Figure yourself on the deck of the *Irene*, with the invisible air stretching between you and the South Foreland, knowing that it contained something which stifled the sound, but not knowing what that something is. Your senses are not of the least use to you; you are unable to see, or hear, or feel, or taste, or smell the object of your search; nor could all the philosophical instruments in the world, as it now is, render you the least assistance. You cannot take a single step towards the solution without the formation of a mental image, in other words, without the exercise of the imagination. Let me unfold my own exact course of thought and action.

Sulphur in homogeneous crystals is exceedingly transparent to radiant heat, whereas the ordinary brimstone of commerce is highly impervious to it. Why? Because the brimstone of commerce does not possess the molecular continuity of the crystal, but is a mere aggregate of minute grains not in pefect optical contact with each other. When this is the case, a portion of the heat is always reflected on entering and 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 in the substance. A snowball is opaque to light for the same reason. It is not optically continuous ice, but an aggregate of grains of ice, and the light which falls upon the snow being reflected at the limiting surfaces of the snow granules, fails to penetrate the snow to any depth. Thus by the mixture of air and ice, two transparent substances, we produce a substance as impervious to light as a really opaque one. The same remark applies to foam, to clouds, to common salt, indeed to all transparent substances in powder. They are all impervious to light, not through the real absorption or extinction of the light, but through internal reflection.

Humboldt, in his observations at the Falls of the Orinoco, is known to have applied these principles. He found the noise of the Falls three times louder by night than by day, though in that region the night, through beasts and insects, 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 30° 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 denser air. This philosophical explanation made it generally known that a non-homogeneous atmosphere is unfavourable to the transmission of sound.

But what on July 3, over a calm sea, where neither rocks nor grass existed, could so destroy the homogeneity

of the atmosphere as to enable it to quench, in so short a distance, so vast a body of sound? As I stood upon the deck of the *Irene*, pondering this question, 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 mixture, I considered in the highest degree improbable. It would be sure, I thought, to streak and mottle the atmosphere with spaces, in which the air would be in different degrees saturated, or it might be displaced, by the 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 cloud threw itself athwart the sun, and shaded the entire space between us and the South Foreland. The production of vapour was checked by the interposition of this screen, that already in the air being at the same time allowed to mix with it more perfectly; hence the probability of improved transmission. To test this inference the steamer was 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 we had the guns fired, both point blank and elevated. The faintest thud was all that we heard, but we did hear a thud, whereas we had previously heard nothing, either here or three-quarters of a mile nearer. We steamed out to $4\frac{1}{4}$ miles, when 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; 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 lightship. Precisely fifteen minutes after we had separated from them the flag was hoisted. The sound, as anticipated, had at length succeeded in piercing the body of air between the boat and the shore.

On returning to our anchored boat we 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.

The conjectured explanation of the stoppage of the sounds appeared to be thus reduced to demonstration, but we pushed the proof still further by steaming farther 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 sound 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.

Steaming on to the Varne lightship, 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. 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 characterises the sound of the large American steam whistle. At the Varne lightship, therefore, the sounds had been heard towards the close of the day, though it is $12\frac{3}{4}$ miles from the signal station.

What is the full meaning of this result? Imagine a man in an anchored boat at 2 P.M. at a distance of 2 miles from the Foreland, and suppose him possessed of instruments which would enable him to measure the growing intensity of the sound. Applying the law of inverse squares, to carry the sound to six times the distance, its intensity at 2 miles would have to be augmented 36 times. But the Varne lightship is more than 6 times 2 miles from the Foreland. Supposing no absorption or partial reflection to occur, the observer would have found that by the lowering of the sun the sound at his position had at 6 P.M. risen to more than forty-fold the intensity which it possessed at 2 P.M. In reality the augmentation was still greater.

(*To be continued.*)

BIRMINGHAM NATURAL HISTORY AND MICROSCOPICAL SOCIETY

AT the annual *soirée*, held on Tuesday, December 16, 1873, celebrating the sixteenth year of the existence of the society, Mr. W. R. Hughes, F.L.S., the president, gave, at the request of the committee, an address on "The recent Marine Excursion made by the Society to Teignmouth." After alluding to the apt and graceful remarks of his predecessor in office (Rev. H. W. Crosskey, F.G.S.) twelve months ago, on the advantages of the study of Natural History, and then describing the preliminary arrangements in connection with the excursion which have already been detailed in NATURE, vol. viii. pp. 334 and 469, Mr. Hughes stated that upwards of 20 members of the society, including several ladies, proceeded from Birmingham and assembled at the headquarters at Teignmouth on Monday, September 1, on which day the dredging operations commenced on board the yacht *Ruby* with satisfactory results. These were carried on during the week, and have already been described in NATURE; the principal feature being the capture of the pedunculate form of *Antedon rosaceus* (*Comatula rosacea*), the rosy feather star, including representatives of 12 genera of Echinodermata and about 40 species of Hydrozoa and Polyzoa, the last of which had been mounted and presented to the society by his friend and colleague, Mr. A. W. Wills, to whom the Society were also indebted for life-like drawings of the *Antedon* in various stages of development.

Mr. Hughes then proceeded to speak of the moral of the marine excursion. So far as he was informed it was the first of its kind that had been undertaken by any society carrying on its operations in an inland district like Birmingham, far removed from the sea, and that point was in itself noteworthy, and might contribute to raise the status of the society and cause its example to be followed by others of a kindred nature. He thought it was pretty well agreed among the members that the excursion was attempted properly, and on the whole carried out successfully. The members who took part in it had been stimulated and encouraged in their project by the hearty and unanimous way in which it was adopted by others whose studies lay in different directions, by praise from NATURE, that most cultivated of scientific serials, and by "good words" from the local press. The results might not have satisfied all. Circumstances rendered the absence of many old supporters of the society unavoidable. It was planned a little too late in the season, and many of the microscopic animals they dredged had played their part in the great problem of life, and empty cells alone remained where many a delicate and beautiful organism had spread its feathery plumes "in the dark unfathomed caves of ocean." Too much time was devoted to the dredging, and not sufficient for subsequent investigation of the proceeds. Still the members had enjoyed the rare opportunity of examining many beautiful marine animals under the microscope which they could not have hoped for at home. And the excursion had done much to promote exchange of thought and friendliness among those taking part in it. Doubtless if a similar one were planned in 1874 the members would profit by the experience of the late one, and Mr. Hughes commended such to the consideration of the committee, and suggested that the members should make it the subject of their annual holiday, especially as ladies were now for the first time admissible as members. The President stated he could not close his remarks to an assembly composed of naturalists and those who had evinced a taste in their pursuits, without alluding to the fact that must have impressed most of them, viz.: that the study of marine zoology had in these days attained an interest second to that of no other branch of natural history, and that the existence and habits of the denizens of "the great and wide sea" were discussed as familiarly in the newspapers of the day as the events of social and political life. As further evidence, Mr. Hughes alluded to the record, almost surpassing any story in the "Thousand and One Nights" contained in that most charming of books "The Depths of the Sea," of the researches in deep-sea dredging, by Prof. Wyville Thomson, F.R.S., and Dr.