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SCIENTIFIC WRITINGS

OF

JOSEPH HENRY.

VOLUME II.



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SCIENTIFIC WRITINGS OF JOSEPH HENRY.

PART II.—Continued.

(1847 to 1878.)

THE METHOD OF SCIENTIFIC INVESTIGATION, AND ITS APPLICATION TO SOME ABNORMAL PHENOMENA OF SOUND.*

(Bulletin of the Philosophical Society of Washington; vol. II, pp. 162–174.)

Delivered November 24, 1877.

GENTLEMEN: I beg leave to tender you my sincere thanks for the honor you have conferred upon me, and the good feeling you have manifested toward me, by my re-election as president of this society. I say the good feeling which you have manifested toward me, because I know that there are many of your members who can much more efficiently discharge the duties of the office than I can. I may perhaps be allowed to say—without the charge of undue egotism, that I have never occupied any position for which I have been voluntarily a candidate. The several offices of honor and responsibility which I now hold—no less than nine in number, have all been pressed upon me without solicitation on my part, and I now begin to feel—in view of that peculiarity of human nature so admirably exhibited in the character of the Archbishop of Granada, that I ought to diminish the number of my responsibilities, gradually leaving to others the honor and the toil of office. It is therefore with no feigned hesitation that I again accept the re-election to the position to which your kindness has called me.

I have however taken from the first a deep interest in the society, knowing that it is intimately connected with the intellectual development of the city of Washington, and that it has a reflex influence upon every part of the United States. It tends to keep alive an active spirit of scientific advancement, not only to diffuse a knowledge of the progress of discovery among its members, but also to stimulate—by friendly criticism and cordial sympathy, to new efforts in the way of explorations into the unknown.

While but comparatively few qualifications are necessary for admittance, yet no person is elected who is not supposed

*[Anniversary address of the president of the Philosophical Society of Washington.]

to have at least a high appreciation of science, some familiarity with its principles, and capability of doing something in the way of promoting the objects of the association.

The general mental qualification necessary for scientific advancement is that which is usually denominated "common sense;" though added to this, imagination, invention, and trained logic—either of common language or of mathematics, are important adjuncts. Nor are objects of scientific culture difficult of attainment. It has been truly said that the "seeds of great discoveries are constantly floating around us, but that they only take root and germinate in minds well prepared to receive them."

The preparation however is not difficult, and many possess the requisites in an eminent degree who are not aware of the fact. Genius itself has been defined as a mind of general powers, determined—enthusiastically it may be, on one pursuit.

The method of discovery or of scientific observation is not difficult. There is a story in a work entitled "Evenings at Home" which produced an indelible impression on my mind. It is entitled "Eyes and No Eyes," and related to two boys who started on a walk during a warm summer afternoon. On their return one was fatigued, dissatisfied, having seen nothing, encountered only dust and heat; while the other was charmed with his walk, which had been over the same ground, and gave a glowing account of the objects with which he had met and of the reflections which were awakened by them. On this story De la Bêche has founded a work, entitled "How to Observe in Geology," which I would commend to the attention of every member of this society, while I suggest that good service would be done to the advance of knowledge were a similar work published relative to all branches of science.

Method of Scientific Investigation.—The first requisite for an observer is that his mind should be actively awakened to the phenomena of nature with which he is surrounded. Thousands of persons of excellent mental capacity pass through the world without giving the slightest attention to the ever

varying exhibitions which are presented to them. The sun rises and sets, the seasons change, the heavens every night present new aspects, but these to them are matters of course; they excite no interest, and it is only when some extraordinary phenomenon occurs, such as the blazing comet or the startling earthquake, that their attention is arrested. Another requisite is the power of the perception of truth, which enables the observer to recognize and define with unerring accuracy what he has seen without any tinge of color from *à priori* conceptions. Still another is the faculty of eliminating accidental conditions from those which are essential; and further, the characteristic of perseverance is indispensable.

The fields of scientific labor may be divided into two classes, viz., those which relate to the empirical observation of facts and those which relate to the systematic series of investigations as to the law or cause of special phenomena. As illustrations of the first class, may be specified the facts of the phenomena of the physics of the globe, those of ordinary meteorology and natural history; while as examples of the second, we have the phenomena of chemistry, physics, and astronomy.

The remarks I have previously made refer principally to the former. In order to elucidate the method of investigation, in the latter case, I will suppose the existence of a new phenomenon which is unconnected with any of the present generalizations of science, but of which it is desired to discover the law, or the facts with which it is associated. Such facts standing alone form no part of science; they are usually discovered in the course of investigations, and are of great importance in pointing out fields of new research which promise an abundant harvest.

The first step in the investigation is to re-produce the phenomenon; the next is to form in the mind a provisional hypothesis as to its cause; and in the choice of this we are governed by analogy. For example, if it appears to resemble some of the phenomena of electricity, we *assume* that it is produced by electricity; we next endeavor to ascertain by

what known action of electricity such an effect could possibly be produced: for this purpose we invent an hypothesis, or imagine some peculiar action of electricity sufficient to produce the effect in question; we then say to ourselves, if this be true, it will logically follow that a specific result will take place if we make a certain experiment; the experiment is devised and tried, but no positive result is obtained. In order to this negative result, the logical deductions must have been inconclusive, or the experiment must have been defective, or the hypothesis itself erroneous.

We examine each of the two former steps, and finding nothing amiss in them, we conclude that the hypothesis was not true. Another hypothesis is then invented, another deduction inferred, and another experiment made; still no result is obtained. At this stage of the research the inexperienced investigator is prone to abandon the pursuit: not so he who has successfully attempted to penetrate the secrets of nature. Undeterred by failure, he changes from time to time his hypotheses, makes new guesses, and again repeats the question as to their truth by means of experiment; until at length nature—as if wearied by his solicitations, grants him a new and positive result. He has now two facts, and an hypothesis to explain them; from this hypothesis he makes a new deduction, which is also tested by a new experiment; but now perhaps he obtains a result which although of a positive character, is not what he expected. He has however made an advance; he has three facts and an hypothesis to explain two of them. In this case he does not usually abandon his preconceived idea, but modifies it until it includes the new fact. With the hypothesis thus improved, he deduces—it may be in rapid succession, a number of new conclusions, the truth of all of which is borne out by the results of the experiments. The investigator now feels that he is on the right track; that the thread of Dædalus is in his hand, and that he will soon be in the full light of day: but usually the escape from the labyrinth is not so easy. In the height of his successful career it not unfrequently happens that a result is obtained diametrically op-

posed to his previous generalization, which conclusively forces upon his mind the conviction that he is still far from attaining his end; that he has not yet seized upon the fundamental principle of the phenomena, which have grown into a class under his hands.

At this stage of the inquiry his self-esteem is much depressed; he throws aside for a while his apparatus, refers to his library for new suggestions: the subject however is not discharged from his mind; it still goes with him, and is perpetually recurring; it is mingled with his dreams, and is seen associated with the every-day occurrences of life, until at length, in some happy moment of inspiration, it may be after refreshing sleep, the truth flashes upon him; he catches a more extended conception of the relations of the phenomena; a more comprehensive hypothesis is suggested, from which he is enabled to deduce in succession a large number of new conclusions to be submitted to the test of experiments. These are all found to yield the expected results, and the generalization which has thus been obtained is more than an hypothesis; it is entitled to the name of a verified theory. The investigator now feels amply rewarded for all his toil, and is conscious of the pleasure of the self-appreciation which flows from having been initiated into the secrets of nature, and allowed the place not merely of an humble worshipper in the vestibule of the temple of science, but an officiating priest at the altar.

In this sketch of a successful investigation which I have given, it will be observed that several faculties of the mind are called into operation. First, the imagination—which calls forth the forms of things unseen and gives them a local habitation, must be active in presenting to the mind's eye a definite conception of the modes of operation of the forces in nature sufficient to produce the phenomena in question: second, the logical power must be trained, in order to deduce from the assumed premises the conclusions necessary to test the truth of the assumption in the form of an experiment: and lastly the ingenuity must be taxed to invent the experiment or to bring about the arrangement of apparatus adapted to test the conclusions.

These faculties of the mind may all be much improved and strengthened by practice. The most important requisite however to scientific investigations of this character, is a mind well stored with clear conceptions of scientific generalizations, and possessed of sagacity in tracing analogies and devising hypotheses.

Without the use of hypotheses or antecedent probabilities, as a general rule—no extended series of investigations can be made as to the approximate cause of casual phenomena. They require to be used however with great care, lest they become false guides which lead to error rather than to truth.

It is not enough for a physical investigation that we have the simple idea, which may be embodied in a mathematical equation; we must see clearly with the mind's eye the operations in nature, and how the phenomena are produced in accordance with the well-known laws of force and motion.

An Investigation of an Acoustic Phenomenon.—As an illustration of what I have said, as well as an original scientific communication, I may be allowed to present in this connection an account of some observations on the phenomena of sound in its application to fog-signals, in which I have been engaged during the past summer, and which are an extension of the investigation of whose progress I have given an account at different times to the society.

This year my attention was again directed to the peculiar effect observed for several years past on the coast of Maine, which has been classed among those to which the term "abnormal phenomena of sound" is applied. In August, 1873, this was partially examined, and the result published in the Light-House Report for 1874. In order to investigate it further, I associated myself with General J. C. Duane, engineer of the first Light-House district; Commander H. F. Picking, inspector of the same district; Mr. Edward L. Woodruff, assistant engineer of the third district, and Mr. Charles Edwards, assistant engineer of the first district.

The phenomenon to be investigated was exhibited in connection with the fog-signal at a station called Whitehead, on

the coast of Maine, at the entrance of Penobscot Bay. It was reported as having been frequently experienced by the captains of the steamers plying between Boston and New Brunswick, and it had also been observed on two different occasions by officers of the light-house establishment.

The phenomenon, as reported by these authorities, consisted in hearing the sound of a ten-inch whistle distinctly as the station is approached till within the distance of from four to six miles, then losing it through a space of about three miles, and not hearing it again until within about a quarter of a mile from the instrument, when it suddenly becomes audible almost in its full power.

This phenomenon—according to the statement of the keeper of the light-house station, is noticed whenever the vessel is approaching the station from the south-west, and the wind is in the same direction. It is especially observed during a fog (when the warning of the signal is most wanted), and this is here always accompanied by a wind from the south or southwest.

Our first object was to verify the phenomenon, and for this purpose we steamed to the south-west, directly against the wind, which was blowing at the time with a velocity of about ten miles per hour; this fortunately happened to be the direction of the wind during which the phenomenon was most frequently observed. The whistle was sounded every minute by an automatic arrangement, and the time at which the several blasts were given could be noted from the vessel by the puffs of steam emitted by the whistle. As we increased our distance from the signal the sound very slightly diminished in loudness until the distance was about a half mile, when it suddenly ceased to be heard, and continued inaudible for about a mile farther, when it was faintly heard, and continued to increase in loudness until we reached the distance of four miles; at this point it was heard with such clearness that the position of the station could be readily located in the densest fog, but on proceeding still farther in the same direction it gradually diminished and was finally again lost.

As a second experiment we re-traced the same line back to the station, and observed the same effects in a reversed order. The sound was heard the loudest at a point about four miles from the station, and after that it diminished and became inaudible through a space of about two miles, and then suddenly burst forth nearly in full intensity at a distance of a quarter of a mile, and continued loud until the station was reached.

For the investigation of this phenomenon, we may assume provisionally that it is due to a peculiar condition of the atmosphere, either as to heat, pressure, or moisture, or a combination of all of them, which existed at the time in that part of the track of the steamer which may be denominated "the region of silence." But if this were true, such a condition of the atmosphere ought to be indicated by ordinary meteorological instruments. To test this, the temperature of the air was noted through the whole space by an ordinary thermometer, and also its pressure by means of an aneroid barometer, but no variation was observed in these instruments in passing through the air along the path of the vessel.

To complete this series of observations however the indications of a delicate hygroscope should have been noted. Unfortunately we were not provided with an instrument of this kind; the fact however that the phenomenon was frequently observed during a fog, or while the air is uniformly saturated with moisture, indicates that the phenomenon is not due to a difference of moisture in the region of silence. Indeed, it is sufficient to remember that a wind was blowing at the rate of ten miles an hour to be convinced that an isolated portion of air could not remain in a fixed position, even for an instant.

Another hypothesis might be assumed,—that the apparent silence was caused by the transverse reflection, in some way, of sound from the shore, but there was nothing in the configuration of the land which favored such an hypothesis.

The only explanation which presented itself was that of the upward refraction of sound, an hypothesis which has been

found fertile in new results in previous investigations of the same subject. To test this and to ascertain the dependence of the phenomenon on the wind, the position of the focus or the origin of the sound was changed. For this purpose the whistle of the steamer was sounded while a portion of the observing force was placed at the station; by this arrangement it was found that while the vessel, in reference to the sound of the signal at the station, passed through a region of silence, the observers at the station who gave attention to the sound from the steamer heard no interruption of the signal. This experiment was repeated each way, going to and coming from the station.

From this result it appears that the sound going *with* the wind was heard at every point on its course, while the sound moving against the wind was suddenly lost at a given point and not recovered again until a distance of more than a mile had been traversed by the vessel. This result was in strict conformity with the theory of refraction; in the case of the sounds travelling against the wind, the upper part of the wave would usually be more retarded than the lower, and consequently the sound wave would be thrown upward above the head of the observer. At a given altitude this difference of velocity would cease, and by the general tendency of sound to spread, the sound wave would again reach the earth.

But to test this still further, and to show that the locality was not an essential condition of the existence of the interval of silence, the experiment was repeated on the opposite side of the station, so that the sound from the fog-signal would move in the direction of the wind. Some of the observers were placed at the station and the others remained on board the vessel; both instruments were sounded, the one in the intervals of the sounding of the other.

In this case the sound from the fog-signal was continuous to those on board of the vessel through a distance of over four miles, and could probably have been heard many miles farther, but the progress of the steamer in that direction was stopped by the land.

From the report of the observers at the station it appeared that as the vessel passed into the distance but one blast was heard during its whole course. In this case (as in the preceding experiment of sailing to the south west) the sound moving against the wind was refracted upward, and as the whistle was but six inches in diameter it did not give sufficient volume to again reach the earth by spreading.

In experiments of previous years the fact has been shown that the sound is heard under certain conditions better when moving against the wind than in the opposite direction. This was notably the case in the experiments made at Sandy Hook in September, 1874, during which a sound from the west was heard at first *with* the wind about three times as far as a sound from a similar source was heard from the east, or *against* the wind; then the same sound was heard from the west three times as far as from the east after the wind had settled to a calm; and in a third observation the same phenomenon was observed after the wind had changed to a direction *opposite* to that of the sound, and had increased to a velocity of ten miles an hour from the east. These effects were afterwards shown to be connected with the fact that the upper wind during the whole day was blowing strongly from the west, and that the apparent changes of the wind were due to currents at the surface, and thus a sufficient explanation was given to the phenomena observed.

It would appear however from the investigations of last summer that the wave of sound which has been refracted upward may descend at a greater distance from its origin than even that at which sound moving with the wind can be heard, probably involving a peculiar case of undulating or compound refraction; but this requires further investigation.

Each series of observations gives rise to new questions, and indicates that the subject is one which is rich in new results. Unfortunately however the observations can only be made by the aid of steamers; and these—in the Light-House service, can only occasionally be employed in the rare intervals of more imperative duties.

In order to collect data for further use in the explication of the phenomena, the light-keepers at Block Island and Montauk Point (the eastern portion of Long Island) have been directed to blow the fog-signals for an hour on every Monday morning, each noting whether he can hear the sound from the other station; observing at the same time the direction of the wind and the apparent motion of the clouds.

From the result of these observations during the year it appears that the clouds give frequent indications of adverse wind currents, and that the number of times the sound has been heard against the wind is greater than the number of times it has been heard with the wind; a result which though unexpected—is not in discordance with previous assumptions.

It will be recollected by the Society that I have in previous years mentioned a remarkable phenomenon, which I have denominated the "*ocean echo*." This has also been observed by the distinguished scientific adviser of the Trinity Board, and is considered by him as the key of all the abnormal phenomena of sound observed, and as a special illustration of the truth of his hypothesis that such abnormal phenomena are produced by invisible clouds of flocculent atmosphere. The phenomenon in question consists in a reverberation in the form of an echo from a point in the verge of the horizon to which the axis of a fog-trumpet is directed.

In regard to this, I first adopted the provisional hypothesis that this was produced by a reverberation from the crests of the waves of the ocean; but it having been stated that the same phenomenon is exhibited while the sea is smooth, this assumption must be abandoned, or in some way modified to suit the observed facts. To test the hypothesis of the reverberation being due to a reflection from an invisible cloud on the verge of the horizon, the trumpet of the large siren on Block Island was gradually elevated from a horizontal to a vertical position, and while in this position it was sounded at intervals for several days; but in no case was an echo heard from the zenith, but in every instance an

echo was returned from the horizon around its whole circumference.

In another experiment with a vertical trumpet at Little Gull Island, a small cloud, from which a few drops of rain fell on the area of the base of the light-house, passed directly across the zenith, and during this passage no echo was observed from the cloud, although the trumpet directed toward it was sounded several times in succession.

Again, in order to obtain additional facts in regard to the nature of this echo, observation was made from a vessel, by steaming out directly as if into the region of the echo—*i. e.*, in the direction of that point in the horizon from which the echo appeared to emanate.

In this case the loudness of the echo appeared to gradually diminish as we advanced, and to spread itself through a much longer arc of the horizon, while the duration of the echo increased in time.

It would follow from this experiment that the echo is not a reflection from a definite surface, since it would then increase in loudness as the surface is approached, but a series of rebounds from points at various distances.

Another fact of great importance in determining the nature of the echo is that derived from the observations of the keeper at Block Island. He has recorded every Monday during a year, the observations of the length of the continuance of the echo, the state of the weather, the direction of the wind, and the other meteorological data. Whence it is found that the echo from the sound of the siren is always heard during a wind in any direction, and of all intensities, but during the occurrence of a very high wind, with less duration after the original blast, than in calmer weather; and above all, that it is heard equally well during a dense fog, when evidently the air must be homogeneous and saturated in every part with vapor.

From these facts it appears to me conclusive that the reverberation, constituting the *ocean echo*, cannot be due to invisible clouds. The only hypothesis suggesting itself to my mind as a basis for further investigation of this subject

—is that in the spread or divergency of the sound, the direction of the impulse turns through an angle of a little more than 90°, so as to meet the surface even of the smooth ocean in a direction by which it would be reflected to the ear of the observer, making the angle of reflection equal to the angle of incidence; although from the gradual dispersion of sound-beams, the precise equality of these angles is obviously not very important to the result.

On returning from this excursion by the N. Y. Western railway to the Hudson river at Troy, opportunity was taken to make some observations on the action of sound in the Hoosac tunnel, through which I passed, on the afternoon of September 7th, accompanied by Mr. E. L. Woodruff. Resting at East Windsor, near the western outlet, I spent a considerable part of the following day in making an examination of the work. Mr. W. P. Granger, the chief engineer, and Mr. A. W. Locke, his principal assistant, very courteously furnished a hand-car, and cordially proffered every facility for making any desired investigations. This tunnel (as is known to most of those present) is nearly five miles long, rising by an easy grade of 26·4 feet to the mile from either mouth to about the middle of the tunnel, where it opens into a vertical ventilating shaft through the rock—of upwards of a thousand feet in height. The top of this shaft opens between two ridges of the Hoosac Mountain, which rise respectively some 400 and 700 feet higher. From the middle of the tunnel when entirely clear of smoke, the distant opening at either end appears as a faint star. The darkness seems oppressive; and when a train is passing through, the air becomes so thickly clouded that the glare of torches cannot be seen at a distance of more than a dozen feet.

It had been constantly observed by those employed in the tunnel, that during the approach of a locomotive at no great distance, and a few minutes afterward, the sound of the engine was very much deadened and obstructed; so much so indeed as to imperil the workmen engaged in lining the top of the tunnel with a brick arch, who frequently failed to hear the locomotive until it was close upon them. This ob-

scuration of sound was not unnaturally attributed to the dense clouds of smoke constantly emitted by the locomotive; but this explanation can hardly be accepted as the true one, nor the condition noted as constituting even an appreciable cause of such acoustic opacity. When we reflect that a puff of exhaust-steam at high temperature is ejected at about every four feet of rail traversed by the driving wheels, it is not difficult to realize that in an atmosphere so systematically made heterogeneous there must be a very great amount of dispersion and absorption of sound waves struggling through such a medium. This has been well illustrated by the striking experiments of the distinguished physicist of the Royal Institution. A very simple method of confirming this explanation, and of eliminating entirely the effect of the smoke, would be the employment of locomotive engines driven by the combustion of coke or of charcoal. This experimental determination of the question did not occur to me till after we had left the tunnel; but on suggesting it to Mr. A. W. Locke, the assistant engineer in charge, he very obligingly undertook the conduct of such an experiment at the earliest convenient opportunity. The result has not yet been ascertained.

When the tunnel was entirely clear, and a gentle current of air flowing down the central ventilating shaft and out at the two ends (as is usual in the summer season, when the external temperature is higher than the internal), it was observed that a prolonged but irregular echo followed any loud noise, such as the sudden shutting down of the lid of a tool-chest. The unequal or somewhat intermittent character of the echo appeared to result from the irregular surface of the rock forming the walls of the tube. A somewhat similar echo is sometimes returned from the dense foliage of trees. It is proper to add that a very perceptible echo was heard from the portion of the tunnel lined with brick. The effect could in neither case be ascribed to any invisible "flocculence," as the air must have been in a very homogeneous condition.

Inasmuch as in such observations the waves of sound are

reflected back to the ear from points at a considerable distance from their origin, (this being especially true of the ocean-echoes,) we are liable to be seriously misled if we rely too confidently on the experiments of the laboratory, and form hasty generalizations from apparent analogies, without carefully considering *all* the meteorological conditions by which the rays of sound may be deflected, distorted, and diverged. It is now well established by numerous observations and experiments—made independently on both sides of the Atlantic, that the lines of acoustic propagation (conveniently called sound-beams) which are sensibly very rectilinear for the distance of a hundred or two hundred feet, and which are thus obedient to the katoptric and dioptric laws of precise focal convergence, by means of solid mirrors and of gaseous lenses, are yet at the distance of a few miles so strangely contorted and aberrant as seemingly to contradict all the analogies suggested by our experience with the rays of light. It is the accumulation of comparatively slight divergencies continued through many thousands of yards, whether under the influence of constant conditions or of changing and reversed conditions, which produces such marked anomalies at the distance of five or of ten miles, and which makes their investigation as laborious as it is instructive and important. And not until we have mastered all the conditions affecting the transmission of sound throughout its entire sensible range, and have thus become enabled to predict its true course, and to announce its varying limits of audibility at the earth's surface, under given circumstances, can we be said to have perfected the theory of this most interesting and indispensable agent of communication.