Thomas Stevenson, C.E. By Professor Swan.

(Read July 15, 1895.)

Thomas Stevenson was born in Edinburgh on the 22nd July 1818. His and my own grandfather was Thomas Smith, the first engineer to the Board of Northern Lights; and his father was Robert Stevenson, who succeeded Mr Smith in that office, which he held for the long period of forty-five years, and who was the designer of the Bell Rock Lighthouse. This tower, built under his personal superintendence before the days of steam navigation, on a low-lying reef continually submerged during neap-tides, was a work of peculiar difficulty, and its successful accomplishment an achievement probably not yet surpassed in lighthouse construction.

Thomas Stevenson and I received our first schooling from Alexander Brown, then well known in Edinburgh as a highly-accomplished teacher of English, but who was also an exceedingly severe disciplinarian. Neither of us suffered much from Brown's tawse, even although they were not only in continual use in inflicting *palmies*, but also not unfrequently in what might be termed unlimited flogging. But Tom had rather frequent experience of being "kept in" after school hours, on account of lessons imperfectly prepared; and, in years long after the times of Brown and of the High School of Edinburgh, might be heard to say that none of the troubles and trials of his manhood were so hard to bear as the sufferings he had endured at school. School discipline in those days was indeed too often a system of merest terrorism and repression, or repressive terrorism. I have a lively recollection when a book, then familiarly known as *Ruddiman's Latin Rudiments*, was first put into my hands, how I had a strong desire to discover whether any occult relation subsisted between the words "Ruddiman" and "Rudiments." But I dared not ask my tutor, to whom putting questions was a crime, and who would have ordered me reprovingly to hold my tongue and mind my lesson.

From Brown's school Tom proceeded to the High School of

Edinburgh, where he received the education in classics which that institution afforded. Throughout, like many others of its scholars who in after life have distinguished themselves, his position was at best that of respectable mediocrity. Yet he succeeded in accomplishing what, in those days at least, was not so very common. He carried away with him some knowledge of Latin, which he was able to revive and heartily enjoy in later years. A predilection for letters, although doubtless inherited, was, in spite of his stern discipline, evoked into conscious activity by his master, Alexander Brown, and must have received further development at the High School; for, from an early period, he displayed a noteworthy love of books, and early became an ardent book collector. In these days it was far easier than it now is to pick up old books at moderate prices; and, even within the very limited means placed at his disposal, he evinced much good taste and judgment in his purchases. Among these was a copy of *Æsop's Fables* with Bewick's woodcuts, now in my possession. But his chief triumph was falling in with a copy of the excessively rare *Croniclis of Scotland* of Hector Boece (Edinburgh, 1527).

In default of becoming an engineer like his father—an aspiration which as yet had received no encouragement—it was but a natural outcome of his love of letters, and still more of their material embodiment in the shape of books, that he should now have contemplated the calling of a printer as a possible alternative. In accordance with such prospects, about this time he had got made for himself a working model of a printing press. This was not a mere toy, but a regular "Columbian" press; and his notion was to write essays of his own, and to print them. I remember one fragment which thus went through the press. It was written in typical Johnsonian English, due to the inspiration of *Rassellas, Prince of Abyssinia*, and other writings of the great lexicographer, caught under the contagious enthusiasm of Alexander Brown. But a ready use of his fingers, unless it were in writing, was not one of Tom's natural gifts, and the work of compositor and pressman was speedily abandoned.

But now it was time that he were choosing a calling for life. His tastes and aspirations were for his father's profession. But already his elder brothers, Alan and David, had adopted it; and it seemed

as if there were not room left for Tom. Accordingly he chose, at least provisionally, what he liked next best, and was received, without a regular apprenticeship, into the printing-office of Dr Patrick Neill, his father's much esteemed and life-long friend. Here he found, I believe, sufficiently congenial employment, and the days went pleasantly by, but varied by, at least, one sufficiently startling experience. One morning when on his way to the printing-office in the Old Fishmarket Close, when it was blowing a furious gale of wind, a heavy chimney-pot from some of the lofty High Street *lands* fell so close to his feet that a fragment of it rebounding from the pavement, cut his dress, but happily without striking his body; and thus it may be said that his temporary typographical pursuits had in more ways than one nearly lost him for his great life's work as an engineer. Now, however, he entered his father's office before he had completed his eighteenth year.

He afterwards superintended the construction of various works, among which was the lighthouse on Little Ross Island; and it was while thus engaged that he wrote a paper on the geology of that island. This was published in 1843; but a still earlier paper, which appeared in 1842, "On the Defects of Rain-gauges, with the description of one of an improved form," was the first of a series of writings, in course of time, contributed to various scientific societies and journals embracing a very wide field, and which included lighthouse and harbour engineering, lighthouse optics, experiments on the force of waves, meteorology, and other subjects. In 1846 he became a partner with his brothers Alan and David, of whom the former, who had succeeded his father as engineer to the Board of Northern Lights in 1843, in 1853, owing to ill-health, resigned that post, when his brother David was appointed in his place as engineer to the Board, and in 1855 Thomas was conjoined with David in the engineership. During their joint tenure of office, extending over a period of thirty-two years, they designed and erected numerous beacons and lighthouses, among which the lighthouses on Dhu Heartach and the Chicken's Rocks were works of no ordinary difficulty. During his brief term of active professional work, Alan Stevenson had designed and personally superintended the erection of the magnificent lighthouse tower on the Skerryvore Reef, and had also introduced into the Scottish light-

house system Fresnel's dioptric apparatus, on the construction of which he made some important improvements, among which were the employment of diagonal in place of rectangular joints in Fresnel's refractory apparatus, and with the same object—namely, of obtaining more uniform distribution of light—diagonal astragals in the lighthouse lanterns. With a like spirit his successors remodelled many of the earlier Scottish lighthouses, replacing the older reflector apparatus by the lenses and other agents of the dioptric system; and it was in this work that Thomas achieved the well-earned and world-wide reputation of being first in his time in the improvement of lighthouse apparatus, "by whose devices," it has with literal truth been said, "the great sea-lights in every quarter of the world now shine more brightly."

Augustin Fresnel (B. 1788), in June 1819 placed by the Government of France on the Commission des Phares, in August of the same year submitted to the Commission his design of a polyzonal lens, which he proposed should supersede the reflectors then in use in the lighthouses of France. Owing to the then imperfect condition of the art of glass-working, difficulties were at first experienced in the manufacture of these lenses, which were only overcome by new methods of Fresnel's own devising; and it was not until July 1823 that the famous old lighthouse tower at Cordouan, where it had been determined to inaugurate the new system of lighthouse illumination, was lit up by means of lenses in place of the reflectors which had served since 1799.

Meanwhile Fresnel had communicated to the Academy of Sciences, on 29th July 1822, his *Memoire sur un nouveau systeme d'eclairage des Phares.* This, the only considerable published writing on his "new lighthouse system" proceeding from his own pen, consists in a description of his polyzonal lenses and their arrangement for revolving lighthouse apparatus, where, in order to save light which would otherwise be lost by upward divergence, each large lens is accompanied by a smaller one placed above in connection with an inclined mirror, the effect of the arrangement being to increase the duration of the flash from the great lens.

But he died in 1827, and thus but the five remaining years of his brief term of life were afforded him in which to work out his dioptric system of lighthouse illumination; but in these years the

optical agents which he had devised—each perfect of its kind—were two in number,—his polyzonal lens, in which the centre and radius of curvature for each zone are separately computed, so as almost entirely to get rid of spherical aberration, and his totally reflecting lighthouse prisms. But the application of these agents to the design of his fixed light apparatus he did not live to see actually constructed in all the details in which he had conceived them. It was not until further experience in the manufacture of lighthouse apparatus had rendered it practicable that his designs were for the first time carried out in Scotland by Alan Stevenson, and then, as at length constructed after what we cannot doubt was Fresnel's own ideal design, his fixed light apparatus may be regarded as a thing perfect of its kind. Similarly, his revolving light arrangements, as they left his hands, more especially when viewed in the light of subsequent improvements, wear the aspect of being but a first attempt; and, accordingly, Alan Stevenson when contemplating the arrangements to be made for his lighthouse of Skerryvore, dissatisfied with those of Fresnel, introduced the substantial improvement of adding fixed prisms below Fresnel's revolving lenses, these Fresnel-prisms, manufactured in Paris, being the first ever constructed for the large dimensions of a first-order light. Had Fresnel's life been prolonged, there is every reason to believe that the dioptric system of lighthouse illumination would have received further development at his own hand; but now, when that hand was for ever still, the distinction of being his chief successor in the work of improving lighthouse optical apparatus did not fall to any one among his own countrymen, but was reserved for Thomas Stevenson, the subject of this memoir.

This life's work, judging from the date of his earliest publication on the subject, may be said to have begun in 1849, even before his appointment as one of the engineers to the Board of Northern Lights, and to have been continued, so long as health permitted, up to within a few years of his death in 1887. Always on the outlook for improvements, and more especially while under the fresh stimulus arising out of the erection of some new lighthouse, his singularly active mind was continually suggesting something new. In the course of years his inventions, greater and smaller, arising in this way became so numerous that it is scarcely possible in a brief

notice such as the present to give any really adequate account of them, and for the best available information regarding them reference may be made, once for all, to his *Treatise on Lighthouse Construction and Illumination*, of which the third edition was published in 1881. Yet the history of inventions has seldom failed to be interesting to a numerous class of readers; and here it seems desirable at least to point, in chronological order, to Thomas Stevenson's principal lighthouse improvements.

Of these the earliest, made in 1849–50, was the invention of his Catadioptric Holophote. This consisted in the removal of the posterior portion of the parabolic reflector hitherto in use in lighthouses, replacing it by a spherical reflector behind and concentric with the flame, so as to reflect the light incident on it back through the flame along with a lens in front, by which means he contrived that, while by far the greater portion of the original parabolic mirror was retained to fulfil its function of reflecting a beam of parallel rays, the very large portion of light which hitherto had wastefully escaped by natural divergence, was now also emitted in the same beam of parallel rays with that reflected by the parabolic surface. Thus, for the first time, the whole "sphere of rays" diverging from the flame was utilised by being combined into a single beam of parallel rays, with the least possible number of reflections or refractions. The merit of this contrivance will best be appreciated by comparing it with previous attempts made to increase the efficiency of the parabolic lighthouse reflector. It is the first of various arrangements which Mr Stevenson devised in order to intercept, and by the least possible number of optical agents to render parallel, *all* the rays proceeding from a focal point, and which accordingly he termed "holophotal."

In designing a lighthouse where a portion only of the horizon and not the whole all round was to be lit up, the catoptric system of illumination presented no difficulty. It was enough to fit up a system of reflectors embracing in their range the arc to be illuminated and no more. But it is otherwise with the dioptric system. A portion only, instead of the entire Fresnel's fixed-light apparatus, doubtless, can be constructed. But then those rays proceeding from its great central lamp, amounting it may be to more than one-half, which this partial apparatus fails to intercept, will be uselessly

scattered in landward directions—never, indeed, escaping from the lantern, which in that aspect is always constructed of metal or other opaque material. It was to save, as far as possible, this intolerable waste that Alan Stevenson, in Sanda Island Lighthouse, which was lighted in 1850, introduced a large spherical mirror of silvered glass of, I believe, 5 feet 10 inches radius, concentric with the flame, so as to *reflect back through the flame* the light which otherwise would have been wasted. It is obvious that rays thus reflected back will proceed forward thereafter *from the flame*, just as if they had been emitted directly by it, and thus they will fall on the optical apparatus in front in such directions only as will enable it to transmit them to the seaward horizon. Whether this method of reflecting light back through the flame was thus for the first time employed in lighthouse engineering, I am not aware; but Mr Stevenson has stated (*Account of the Skerryvore Lighthouse*, p. 293) that it had been originally suggested by him so far back as 1834.* We have already seen that this device was also in 1849–50 adopted by Mr Thomas Stevenson in the construction of his Catadroptric Holophote, of which it forms an essential element. He, however, for the purpose of returning back light through the flame did not long rest contented with ordinary mirror-reflection. Having accidentally noticed the brilliant specular look of light emerging from a glass prism, where it had undergone two internal *total* reflections, he conceived the idea of constructing the spherical mirror in his holophotal apparatus of such prisms; and, accordingly, having consulted me, I assigned their proper form and mode of combining them, so as to form a totally reflecting hemisphere (*R.S.S.A. Trans.*, 1850, vol. iv. p. 20). But it was only at a considerably later period that the first complete catadroptric mirror was constructed for the Commissioners of Northern Lights by Mr J. T. Chance, and it was shown by them at the London International Exhibition of 1862. For this instrument Mr Chance devised a new arrangement of the prismatic zones, which greatly facilitated its construction. Their figures were now generated round a vertical instead of a horizontal axis as formerly, and they no longer formed a continuous hemisphere, but were separated from each other. Having thus devised the means of

* This was in a Report to the Commissioners of Northern Lights, 10th December 1834, p. 28. Edinburgh: Printed by Neill & Co., 1835.

reflecting the "back" rays of the flame in his holophotal apparatus arrangements by dioptric agency to the exclusion of metallic reflection, the next problem which suggested itself to Mr Stevenson was how to obtain a dioptric arrangement which should be capable of dealing with *the whole* of the front rays, hitherto in part subjected to metallic reflection. A Fresnel polyzonal lens had, indeed, received the central pencil of these rays, diverging all round the horizontal axis of the lens through an angle of about 45°, which, after refraction, were emitted in directions parallel to that axis. Beyond some such limit of divergence, varying with the kind of glass of which the lens was composed, mere lenticular action was unavailing towards emitting a parallel beam of rays. But now it occurred to Mr Stevenson that the agency of which he was in quest was to be found in Fresnel's catadioptric zones, provided they were generated by revolution round a horizontal instead of a vertical axis; and thus, by means of a Fresnel polyzonal lens surrounded by a series of totally reflecting rings, generated in the manner now described in front and with a totally reflecting dioptric mirror behind, Mr Stevenson obtained a holophote, in which, instead of the optical agents being, as in his earlier invention, partly metallic reflectors and partly lenticular, *all* were now dioptric.

Zones of glass the same in section with those in Fresnel's fixed light, but generated by the revolution of their section about a horizontal instead of a vertical axis, which he had thus devised in order to complete his dioptric holophote, he not unnaturally termed "holophotal."* The two species of zone, although identically the same in section yet differing in their mode of generation, consequently differ in their optical effect. Light from the focal point incident on a Fresnel's fixed-light zone is emitted in every azimuth, but all within a horizontal plane. Light similarly incident on the so-called "holophotal" zone is all emitted in one and the same direction parallel to the axis of revolution of the zone, so that its action is identical with that of a lens in rendering parallel rays proceeding from its principal focus, but capable of producing much greater deviations than lie within the power of any lens. Lenticular action was thus extended from causing deviations from about 45°—the limit of Fresnel's polyzonal lens—to about 130°.

* *Lighthouse Construction and Illumination*, 1881, pp. 83–85.

But it is proper here to mention that zones of this description are said to have been constructed for Augustin Fresnel so long ago as 1826. Yet it would seem that no drawing or description of them was ever published, nor were they ever used in any lighthouse. If they had existed at that early date, there is evidence to prove that they had been forgotten; nor can there be any doubt that they were independently invented by Mr Stevenson.

And now that he had obtained for himself this new and powerful auxiliary, he forthwith proceeded to apply it to the improvement of Fresnel's revolving-light apparatus. This had hitherto consisted in a system of his great annular lenses surrounding the central burner, the light which by upward divergence escaped from their action, and would have been lost, being received on a combination of smaller inclined lenses, which transmit it to plane mirrors overhead, and these finally reflect it outwards towards the horizon, to strengthen the light emitted by the great lenses. Now Mr Stevenson discarded the complex arrangement of the smaller lenses and plane mirrors, replacing it simply by a system of his new holophotal prisms. This capital improvement was first introduced in North Ronaldshay Lighthouse in Orkney, for which the new prisms were made in 1851 by M. Letourneau of Paris. Unquestionably it effected a great saving of light. Fresnel himself, in his *Mémoire* of 1822, had estimated that the loss of the light subjected to the successive action of his lenses and plane mirrors amounted to one-half; while Mr J. T. Chance remarks that in Fresnel's revolving apparatus, as the focal distance of the accessory lenses is less than one-half of the shortest focal distance in the system of reflecting zones, the intensity of the light issuing from the former would be scarcely more than one-fourth of that transmitted by the latter; and, in addition to this cause of inferiority, is the loss arising at the mirrors, so that, on the whole, the modern plan (holophotal) must give light *five* or *six times* more intense than that of the former (Fresnel's) arrangement.

It must suffice here simply to mention that, just as in the case of "Fresnel's revolving light," so also in his "fixed light varied by flashes," similar improvements were effected by Mr Stevenson by substituting holophotal prisms in place of the two-fold refracting and reflecting agents employed in the original apparatus; and it

must suffice also merely to name his "Improved Dioptric Holophote" of 1864 before passing to the consideration of his "Azimuthal Condensing System of Lighthouse Illumination." This, which may be regarded as his crowning achievement in improving on the former condition of lighthouse optical engineering, occupied his attention for a period of fully thirty years (say from 1855 to 1885), during which time he expended on it quite a wealth of inventive faculty, and in the end may be said to have brought about a total revolution in lighthouse construction.

He himself had not exceeded the literal truth when he wrote that "previous to 1855 lighthouse apparatus, having the same illuminating power in every azimuth, was used not only at places where the distances from which the light could be seen were everywhere equal, and where the employment of such apparatus was therefore quite legitimate, but also for places having a searange much greater in some directions than others. This indiscriminate application of apparatus of equal power to the illumination of our coasts necessarily involved a violation of economic principle, for the light was either too weak in one direction or else unnecessarily strong in another." "In other cases, where perhaps only half the horizon had to be lighted, a single flame in the focus of a fixed apparatus could also be strengthened by a hemispheric reflector placed on the side next the land." "But no attempt was ever made to allocate this auxiliary light in proportion to the varying lengths of the different ranges and the amplitudes of the arcs to be illuminated; nor, where a light had to show all round the horizon, to weaken its intensity in one arc, and with the rays so abstracted to strengthen some other arc, which, from its range being longer, required to be of greater power. As none of the agents or combinations which we have as yet described were sufficient for dealing with this branch of lighthouse optics, I found it necessary to devise eight new agents, possessing special optical properties, for distributing the rays not *equally* but equitably" (*Lighthouse Construction and Illumination*, 1881, pp. 97–8).

Some, at least, of these new agents will now fall to be described, and of these the first, taken in the order in which Mr Stevenson has described them, is that which he has termed a "back prism" (*op. cit.*, p. 91).

Fresnel determined the angle subtending the reflecting side of the lighthouse prism by the condition that the paths of the extreme rays of the intromitted pencil of light should be respectively parallel to the sides containing that angle. This construction, although elegant, is not essential to the action of the prism, and is even disadvantageous, as causing the loss of excentric rays, so that the angle of the prism might with advantage be diminished to the needed amount. But another disadvantage of Fresnel's construction is this, that while with prisms so devised by him deviations of light cannot be obtained exceeding from about 100° to 120° according to the kind of glass employed, by freeing ourselves from the limitation which his construction imposes we can quite advantageously obtain deviations up to 120° or 135°. The utility of this in the construction of apparatus to deal with what has been termed "the back light" is obvious; and, accordingly, Mr Stevenson states that the late Mr Alan Brebner and himself had designed what they termed "back prisms," by which rays may be made to deviate from their original direction by about 130°; and he adds, "I communicated the description of these prisms to the Royal Scottish Society of Arts on 6th December 1867.* Professor Swan of St Andrews also independently proposed the same form of prism, a description of which he communicated to the same Society on the 9th December 1867, accompanied by general formulæ for its construction."† These prisms were first used at Lochindal lighthouse in Islay, and were made by Messrs Chance in accordance with Professor Swan's formulæ.

The next of Mr Stevenson's new agents, devised by him in carrying out his azimuthal condenser system of lighthouse illumination, which falls to be described is his Differential Lens. The action of this instrument may best be understood by considering first that of a Fresnel's Polyzonal Lens with the source of illumination in its principal focus. The light diverging from the flame and falling on the plane surface of the lens will, after refraction, be emitted in a beam of parallel, and, it may be assumed, horizontal rays. But if now for the plane face of the lens be substituted a cylindric surface

* *Trans. Roy. Scot. Soc. Arts*, vol. vii., 1868, pp. 540–546.

† This modification was independently suggested by Mr Chance and by myself.

whose axis is vertical, and which therefore is capable of refracting light in horizontal directions only, it is evident that the rays now emitted by the lens will still emerge in horizontal directions, but now no longer parallel to each other, but diverging each from some point of a vertical focal line whose length is equal to the diameter of the lens. The angle of divergence, it is evident, may be adjusted to any required amount by varying the curvature of the cylindrical face of the lense, and just as the central disc and sun surrounding lenticular rings of the Fresnel polyzonal arrangement replaces a simple plano-convex lens ; so, in place of a single cylindrical surface for the differential lens, may be substituted a central cylindrical band bordered on either side by a series of straight lenticular prisms with vertical arcs.

Mr Stevenson's Differential Refractor is the application of the same principle which has been described above for the lens to Fresnel's Cylindrical Refractor; and, for like ends, Mr Stevenson also devised a Differential Refractor, of which, in his own words, "the vertical section must be parabolic, while in the horizontal it must be of such hyperbolic, elliptic, or other curve as will most advantageously give in each case the required horizontal divergence."

Professor Tait was kind enough to investigate the mathematical conditions of the differential mirror, and in the *Proceedings of the Royal Society of Edinburgh* of 1871, he gives by a quaternion integration the formulæ for its construction. For a description of the remainder of Mr Stevenson's new optical condensing agents it must suffice to refer the reader to the descriptions to be found in his *Treatise on Lighthouse Illumination.*

The preceding statement, I believe, will be found to include a tolerably complete enumeration of Mr Stevenson's inventions in lighthouse optics ; but also nothing as yet has been said regarding the application of these to special cases of lighthouse illumination. Many such there are of very great interest; but it is impossible to include any adequate description of them within the limits of the present notice. It must suffice, then, simply to point to one, namely, the Isle Oronsay Light, situated in the narrow and tortuous Sound of Skye. This light, according to the direction from which it is viewed, is visible at very different distances, varying

from 3 to 15 miles. Accordingly, it became an object of importance to distribute the light supplied by an ordinary Fresnel's second-order fixed apparatus, in the various directions in which it was to be viewed in quantity in some measure proportional to the distance it would have to travel to reach the observer's eye, and this was effected by subjecting portions of the light not otherwise usefully available to the action of condensing prisms (*Lighthouse Illumination*, pp. 112–116). The late Mr James Melville Balfour, in reporting on the first trial of this light (October 1857), says, "The prisms throw a light down Sleat Sound superior to any first-class light in the Northern Light's service, and the light up Glenelg Bay is little, if at all, inferior in power" (*op. cit.*, p. 116).

Here it falls to be recorded that Mr J. M. Balfour not only had the charge of the erection of the Isle Oronsay Light, but to him also was committed the working out of the necessary drawings and calculations required in designing it. In this work he obtained invaluable, it might indeed be almost said essential, help from a recent ingenious invention of his own. This was his "Optical Protractor," the first instrument, I believe, of its kind (described in the *Transactions of the Royal Scottish Society of Arts*, vol. v.).*

And here seems a fitting opportunity for remarking how fortunate, in carrying out the application of his new lighthouse agents to actual lighthouse construction, Mr Stevenson was in possessing in the firm's office two such coadjutors as Mr J. M. Balfour and Mr Alan Brebner. The latter, who became a partner in the firm of D. & T. Stevenson, C.E., and died in 1890, was the inventor of a new optical protractor differing from Mr Balfour's. During a period of many years he, along with other assistants in the office, executed the designs for the lighthouses constructed by the firm. Of the value of their co-operation in the work it is impossible to speak too highly.

There still remain unmentioned many of Mr Stevenson's lighthouse inventions, which, being not *purely* optical, have not been included in the preceding enumeration, but space can only now be

* I have elsewhere (in my paper "On New Forms of Lighthouse Apparatus," *Trans. Roy. Scot. Soc. Arts*) expressed my extreme obligation to Mr Balfour for the invaluable aid I had obtained from the use of his ingenious instrument, without whose help I should scarcely have undertaken to protract the designs contained in my paper.

found to mention but one or two of these. The first I will name is that which he has termed "The Apparent Light." This was first designed by him for Stornoway harbour, and erected in 1851. This harbour has a very narrow entrance, whose available width is still further reduced by the presence of a submerged reef. To build a lighthouse on this reef would have been a very costly undertaking, but Mr Stevenson contrived to light up the hidden danger in another way, by availing himself of the already existing lighthouse on Arnish Point. In a window near the bottom of its tower he placed a lens capable of transmitting a horizontal beam of parallel rays to a lantern carried on the top of an iron beacon 25 feet high, which he built on the submerged reef. There the rays are received on a system of vertical prisms, which disperse them seaward over an angle of 62°. It is scarcely necessary to add that the light thus dispersed will appear to the mariner as if it proceeded from an actual lighthouse built on the submerged rock, and not from a lamp placed on the distant shore.

To this enumeration of Mr Stevenson's very varied achievements in lighthouse illumination, I will add the success which crowned his experiments on illuminating beacon or buoys by means of electricity conveyed from land through submarine cables, as fully realised in the lighting of Gedney's Channel, leading to New York Harbour.

Mr Stevenson was a Member of Council of the Scottish Meteorological Society from the time the Society was established in 1855, and its Honorary Secretary from 1871 to his death in 1887. During this long period he not only took an active and earnest part in the management of the Society's affairs, but also made original and permanent contributions to the science of Meteorology. Of these contributions the most important are these:—

1. The Stevenson Screen for the protection of Thermometers, designed by him in 1864. The object sought to be obtained was UNIFORMITY among temperature observations, and in this he succeeded so largely that the Stevenson Screen quickly came into use, and continues to be used extensively in all parts of the world.

2. The introduction into meteorological investigations of the term "Barometric Gradient" in 1867, which he first applied, and with great success, in a discussion of the facts of our great Edinburgh hurricane of January 1868.

3. An elaborate inquiry, with numerous anemometers placed on poles at various heights, into the important question of the rate of diminution of the wind's velocity with height.

4. The proposal, in 1875, to obtain from High Level Stations and Observatories the data for determining "Vertical Gradients" for atmospheric pressure, temperature, and humidity, from their important bearing on meteorological questions generally, but more particularly on weather changes. Ben Nevis Observatory and High Level Observatories of other countries have now been for some time carrying on this great work in a degree and to an extent scarcely in contemplation when the proposal was made in 1875.

The Council of the Society recorded in the Minutes of their meeting of July 11, 1887, their grateful testimony to the vigour and prudence with which Mr Stevenson discharged his duties as Honorary Secretary, and to his unfailing courtesy and readiness to aid and oblige on all occasions.

(*Supplementary*, by D. A. Stevenson, Esq.).

In addition to what has already been stated, should be mentioned his design of a Bivalve apparatus in 1859; also the design and introduction, in 1886, of "Lightning Light" apparatus at the Isle of May electric light, both of which have been strongly advocated since by the engineers of the French Lighthouse Board. But, perhaps, the most notable improvement of recent times is his firm's design of the Hyper-radiant apparatus. This apparatus was designed to take advantage of burners of increased diameter and initial power, and, when tried at the South Foreland in 1885, it was found to be greatly superior to the other lenses tried against it, and is now largely used at home and abroad.

Along with his brother David he made experiments in 1870 on the use of paraffin as a lighthouse illuminant, and after trial at Girdleness Lighthouse, they reported to the Commissioners of Northern Lighthouses that paraffin should be introduced into all the Scottish lighthouses, as its use would increase the intensity of the lights, while their maintenance would be greatly reduced.

Paraffin is now almost universally used in lighthouses. At present prices, and at the present rate of consumption, the use of paraffin in British lighthouses alone results in a yearly saving of between £35,000 to £40,000.

His firm's practice as lighthouse engineers was not confined to the Scottish Board, as their advice was taken by the Governments of India, China, Newfoundland, New Zealand, Japan, and other foreign governments, and schemes for the lighting of the whole coasts of the two last named countries were devised and are now being carried out. In his book on *Lighthouse Construction and Illumination*, the results of the practice of his firm in lighthouse construction and optics are given. For some of his inventions laid before the Royal Scottish Society of Arts, Mr Stevenson was awarded gold medals; but it is perhaps proper to say that for none of his inventions has he, or any member of the Stevenson family, taken out patents, all lighthouse authorities having had free use of their designs and improvements in dioptric apparatus and lighthouse economy generally.

Perhaps I may be allowed to quote the testimony of Captain Sulivan, the professional adviser of the Board of Trade, when in 1861, giving evidence before the Royal Commission on Lighthouses, he stated:—"It is to Mr Stevenson we owe the present state of our lighthouse illumination—for the improvements on the Fresnel light which he has made have really given us the superior class of lights that we have now in England. All that has been done, that I can see, to improve on the system, and to give us a better class of dioptric light, has been done by Messrs Stevenson, and I believe that that is quite the feeling of every one at the Board of Trade."

The practice of the firm, of which Mr Thomas Stevenson was a member, was not confined to lighthouse engineering, as they were mainly engaged in the construction of harbours, docks, and river and estuary improvements. With most rivers and harbours in Scotland he and his partners were in some way professionally connected, while they were also called upon to design works for the improvement of harbours, and of many rivers and estuaries in England and Ireland. To the subject of harbour construction Mr Stevenson directed his attention, bestowing special care in ascertaining the forces which have to be met and overcome in the

erection of works exposed to heavy seas in deep water. He devoted special care to ascertain the force, height, and laws of the propagation of sea waves, and their action on artificial structures. The measurement of the force of the waves was carried out with some degree of completeness by means of instruments which he devised, such as the Marine Dynamometer. The result of his wave observations, and the laws he deduced from them, were given in papers communicated to this Society, to the *Edinburgh Philosophical Journal*, and also in his book on *Harbours*. In 1852, after a series of experiments, he enunciated the law of the increase of the height of waves in relation to "fetch"; other experiments led to formulæ involving the relations between the heights of waves and the various influences which modify them, and also to formulæ by which the reductive powers of harbours and breakwaters—or their power of reducing the height of waves after passing within the entrance—could be calculated, all of which are of great value to the marine engineer. He always held, however, that much remained to be done, especially in ascertaining facts, and he considered his own work in this direction as only approximations. More than thirty years ago he was invited to write the article "Harbours" for the *Encyclopædia Britannica*, which was subsequently published as a separate treatise on *The Design and Construction of Harbours*, and it is now in its third edition.

He came of a well-known family of engineers, all of whom have been highly distinguished in their profession; and his nephew, David Alan Stevenson, was conjoined with him in the engineership of the Scottish lighthouses on his father's resignation, and is now the Engineer of the Board, being the fifth in succession in that office.

He was elected a Fellow of this Society in 1848, acted as a member of Council, as one of its Vice-Presidents, and in 1885 was elected its President. He frequently contributed to our *Proceedings*. He was elected a Member of the Institution of Civil Engineers in 1864; and one of his last literary works was a lecture on "Tides and Coast Works," which he prepared at the request of the Council of that Institution, but which, owing to ill health, he was unable to read. He was a Fellow of the Society of Antiquaries of Scotland, the Geological, and other Societies.

Mr Stevenson was a devoted member of the Church of Scotland. Under the pseudonym of a "Layman," he wrote several pamphlets on religious questions, one of which was reprinted by the late Professor Crawford for the use of his students. He did much in unostentatious charity, many institutions finding in him a warm and generous supporter.

Mr Stevenson was incapacitated for business for a short time previous to his death. He spent the winter of 1886–87 with his late son, Mr R. L. Stevenson, at Bournemouth, returning to Edinburgh only a fortnight before his death, which happened on the 8th May 1887.