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Lighthouses

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Evening Meeting.

Monday, March 16th, 1863.

REAR-ADMIRAL SIR GEORGE BACK, D.C.L., in the Chair.

NAMES of MEMBERS who joined the Institution between the 3rd and 16th March, 1863.

LIFE.

Craig, J., Major Royal North Down Rifle Mil. 9l.
Balfour, F. W., Major late Rifle Brigade. 9l.

ANNUAL.

Clode, C., Esq., Solicitor to the War Office.	Carpenter, G. W. W., Major 32nd
Wynne, G., Colonel R.E. 1l.	Light Infantry. 1l.
Cockburn, J. E., Lieut. R.A. 1l.	Nares, G. S., Commander R.N. 1l.

LIGHTHOUSES.

By A. G. FINDLAY, Esq., F.R.G.S.

In the following remarks, it is proposed to treat of the important subject of lighthouses in a concise manner, as to their present condition. The subject necessarily embraces a very wide range of topics, to discuss all of which, would extend this paper far beyond its assigned limits; therefore, only the principal features will be adverted to. But it will be necessary, in order to make the subject intelligible to all, to advert to points quite familiar to those more initiated, and for which I must claim their indulgence; at the same time stating, that it is almost impossible to bring forward any matter new to those who have made it the business of their lives, and who have given the subject so much thought and study. Beyond the interest which a favourite subject has induced, I have no claims to advance of greater intimacy with lighthouse matters than any one else quite unconnected with them.

The literature of Pharology is very limited, and fifteen years since, scarcely existed. But since 1848, the fine works of Messrs. Stevenson and others have told us the main features of the systems, and are still almost the only English text-books on the general subject. The Parliamentary Report of 1861 has included most of the particulars of the system as in actual operation, but has added little to our previous knowledge, beyond some inferences at variance with previous decisions on the subject, which will be hereafter alluded to. I therefore propose to advert in the first place to the structure; secondly, the apparatus; thirdly, the illumination of lighthouses, appending to these, some observations on the comparative merits of the different points brought forward.

The Structure.—With very few exceptions the buildings erected in early times, for the purpose of directing ships at sea, were of the rude and simple nature of the ships themselves, and very frequently were of wood also. On land these buildings did not differ from ordinary structures, and need no remark. The difficulties encountered in the construction of a lighthouse on a tidal rock, covered and uncovered alternately by the sea, are of course mostly confined to the foundation and the works below the level of high water, and of the action of the waves. These difficulties have been of a most tremendous character, as the narratives of Smeaton and the Stevensons,—of their building the Eddystone, the Bell Rock, and the Skerryvore lighthouses,—most amply declare, but even these are not so exposed or difficult as some later structures which have been completed under the Trinity House.

Of the enormous force of the waves little must be said here. It has been measured at the Skerryvore, having struck an instrument placed for the purpose, with a force of 6,083 lbs. per square foot, and it is almost certain that this is not the maximum force which an exposed lighthouse has to withstand, and nothing but the utmost stability attainable by man, can be hoped to resist it. One often repeated fact must suffice here, as to what a wave can do. At the summit of the new Bishop Rock Lighthouse, off Scilly, a massive bell was fixed by strong iron supports, built into the masonry, at 120 feet above the sea. A wave ascended the tower (as is frequently the case to above the lantern) and had sufficient force to wrench off this bell and break the iron supports, very soon after its erection. All ordinary notions of requisite strength in a building must fall very far short of what is necessary in a building exposed to such forces as these.

Some of the earlier lighthouses on these exposed positions were of wood. Rudyerd's tower on the Eddystone, which lasted forty-seven years, between 1708 and 1755, is an excellent example of the ingenuity of our forefathers, and might have lasted till this time, had it not been destroyed by fire. This is cited, for we have just lost one of the most wonderful structures of the kind, which has been overtaken by modern progress, the Smalls lighthouse off the coast of Pembrokeshire. This most quaint and singular wooden barrack was built by Henry Whiteside, a violin maker, of Liverpool, for Mr. Phillips, a member of the Society of Friends. Whiteside commenced his

work, with some Cornish miners, in the summer of 1772, and from that period, till its demolition in 1862, it maintained its pre-eminently useful existence, amid all the storms and waves which assailed it. The narratives of its occupants and its builders, during the ninety years, of its career, would form a strange series; from the starvation and distress of Whiteside and his companions,—the death of one of the two keepers, whose companion, a cooper, headed him up in a cask, and lived a solitary man with his coffin for four months of stormy weather—to the man whose hair turned white from fright during a storm, which shook the building so as to empty a vessel standing on the table. Yet a most intelligent man, the head-keeper, with a wife and large farm on shore, is found to prefer this station, twenty miles from land, to any other, after eighteen years' residence. One circumstance, about this small freehold, is worth mentioning. When the Trinity House, in 1836, were compelled to purchase it from its private owners, 170,000*l.* were paid for it.

The first stone lighthouse, of its kind, was the Eddystone, commenced by Smeaton, in 1756. Its base only is uncovered at low water, and one of the chief difficulties in its building was to secure the lower courses from the sea, during the progress of the work. They were dovetailed and joggled together in an admirable manner, and each course secured to that beneath it by wooden trenails. As the holes in which these trenails were to fit could not be accurately done on shore, much valuable time was lost in making them on the rock, where minutes are treasures. The same occurred in the building of the Bell Rock Lighthouse, commenced in 1807, but in this case, the workmen lived on the spot in a wooden barrack, somewhat similar to the Smalls Lighthouse. In the much more massive Skerryvore (also built from a wooden barrack) some of these refinements were avoided, and reliance was placed more on the weight and massiveness of the structure, to give it the necessary stability, and the very broad base of the Bell Rock was abandoned for a figure much nearer the form of the Eddystone; thus saving a great amount of labour in the lower courses and foundation. Another advantage, it is thought, has been gained by a more perpendicular side, by its offering a less inviting figure to the waves for ascending the side of the tower.

In the noble towers which have been constructed of late years by the Trinity House, under the direction of the late Mr. James Walker, many of the difficulties and deficiencies of previous towers have been avoided, advantage having been taken of the experience then gained and also much ingenuity in simplifying the details.

The towers more specially noticeable are the Bishop Rock lighthouse, off Scilly, the advanced guard of our southern coasts; the new Smalls Lighthouse, which stood in glaring contrast, by its elegance, with the "strange, wooden-legged, Malay-looking barracoon" which preceded it, and that on the Hanois Rock, off Jersey. These have been erected under the superintendence of the Messrs. Douglass, whose services the Trinity House are most fortunate in securing, as this special branch of engineering requires the skill and energy that these gentlemen possess. They are at present engaged, I believe, in

the most arduous task of erecting a tower on the Wolf Rock, off the Land's End, which only uncovers four feet at the lowest spring tides, the exposed position of which may be judged of when it is said that with all diligence only eighty working hours were available on the rock in 1862.

The great distinction between these towers and their predecessors is that the stones of each course are dovetailed together laterally and vertically, so that the use of metal or wooden pins is needless. On the upper face, and at one end of each block, is a dovetailed projection, and on the under-face, and at the other end, is a dove-tailed indentation. The upper and under dovetails are made just to fall into each other, and when the hydraulic cement is placed on the surface, it so locks the dovetailing that the stones cannot be separated without breaking. Thus, when this cement is set and hardened, the whole of the base is literally one solid mass of granite.

Another advantage of this vertical dovetailing is, that it renders the joint impervious to the action of the waves, a very important point. In former cases this was effected by making a fillet on the outer edge of the lower course, into which the upper course was stepped.

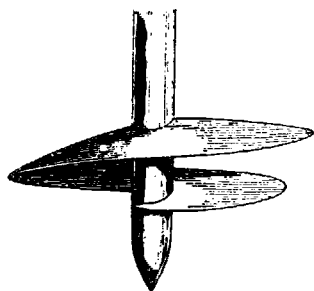
After the rock is prepared for the foundation—one of the most hazardous and difficult portions of the work—the stones are brought, most accurately prepared and fitted to each other on shore, and placed together in their destined positions with very great celerity. In some cases the works progress so rapidly, that two courses have been fixed in one tide.

The lower part of all these towers is a mass of solid masonry, and it is only made hollow at such a height as to secure it from the constant ravages of the sea. The upper part is arranged into several apartments, which need not be adverted to; and crowning all is the light-room, formed of very thick plate-glass set in frames, which are not perpendicular, but are placed diagonally, in order that they may not obstruct the light throughout the whole length.

These few remarks are all that is necessary on the structure, with the exception that it has been argued, and especially by Mr. Alexander Gordon, that there is no need of an extended base, the most costly part of the fabric, but that a simple frustrum of a cone would be preferable as offering a better face to the action of the waves.

The last observation leads to another class of towers, designed and erected by Mr. Gordon, consisting of iron plates bolted together. There are some very fine examples of his lighthouses at Jamaica, Bermuda, the Bahamas, and several other places. These are all excellently well adapted for positions and countries where skilled labour and materials are wanting. We have no experience of an iron tower on a tidal rock, but there is one consideration which would be entertained by the audience, now that the resistance of iron to blows is so much discussed—what would be the effect of a floating spar from a wreck urged end-on to it by the force of the waves?

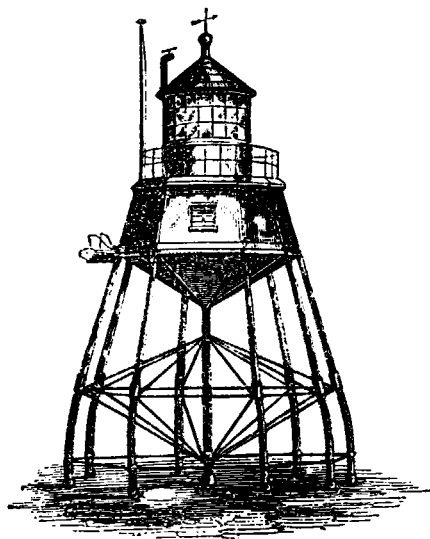
Mr. Gordon's proposition of having all iron lighthouse towers of a uniform scale, so that the plates cast for one should fit the same position in all, is well worthy attention.



Extremity of Mr. Alex. Mitchell's
Screw Pile.

One other form of lighthouse in use must be noticed—the screw-pile lighthouse of Mr. Alexander Mitchell. The Maplin, in the Thames mouth, was the first of these, began in 1838. It stands on nine piles, secured to as many iron screws driven to a depth of 22 feet into the sand. These screws consist of a single turn of a flange, 4 feet in diameter, on the lower end of the iron pile. These were fixed in nine consecutive days under the personal direction of its blind inventor, and by its stability has proved the usefulness of the structure. Other buildings have been constructed

on the same principle at Fleetwood, Belfast, and other places.



The Maplin Lighthouse, erected by Mr. Walker,
upon Mitchell's screw-pile foundation.

A few words may be said on light-vessels. England has more of these than any other country, except the United States; England has 47, the former 48, from the Nore lightship, the first in 1734, in one of the quietest positions, to the Seven Stones light-vessel, in 40 fathoms water, at sea off the Land's End. It is an expensive mode of showing a very imperfect light, but which has hitherto been unavoidable. They have been most useful aids to navigation, though their utility

may be in some degree impaired now that every ship is a floating light-vessel at night, with her mast-head and side-lights. Three men are required for a first-class lighthouse, but 11 men are required to man a lightship, the cost of which is 1,800*l.* per annum, while the lighthouse expense is about 350*l.* per annum.

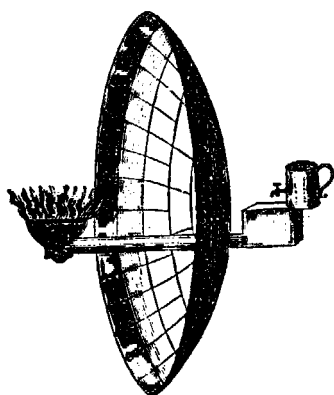
The Apparatus.—This subject is taken in precedence to that of the source of light, because it governs the latter rather than the converse. If light, or flame, could be produced so cheaply as to be not worth while to economise in an expensive manner, there would be no need of those beautiful adaptations of refined optical science, which are now in use. But as the question of making the utmost of every ray has been calculated and reiterated, till I would almost say, deferentially, that it has been overdone, as far as the controlling apparatus is concerned, it has reached a point of perfection beyond which there is little hope of improvement in the present form of apparatus.

It is not forty years since the original coal fire was entirely abolished in English lighthouses. They were wasteful and imperfect, but not entirely inefficient, for in some hazy weather the reflection of the fire, in the air, could be seen when the fire was invisible. The first controlling apparatus was a rude tin reflector placed over the fire, or a polished brass one behind it; but when oil lamps were introduced a more refined system of reflectors was established, on a perfect mathematical principle, which was soon brought into practical use, and still maintains its position.

Liverpool has the merit of having first adopted suitable apparatus for controlling the lamp-lights in its lighthouses, and this too on correct principles. William Hutchinson, a remarkable man, the dock-master there, first applied a paraboloidal reflector to his flat-wicked lamps, at some period between 1763 and 1767. An anecdote states, that prior to this a convivial company of scientific men met at Liverpool, and one of the company present wagered that he would read a book at the distance of 200 feet by the light of a farthing candle. This wager was won by means of a wooden bowl lined with putty, in which facets of looking glass were embedded and formed a reflector. Hutchinson was present, and seizing the idea, utilised it for his lighthouses. His reflectors were formed of tin plates or of wood lined with looking-glass, the largest 18 feet in diameter and 6 feet focus, placed behind a "spreading burner mouth-piece 14 inches broad." The Bidston, Hoylake, and Leasowe lighthouses were thus illuminated, and there is no doubt were most excellent lights for the period. It has been said that 1783 is the date of the first suggestion by M. Tullère in France, but England has this claim for the English system.

When the cylindrical wick'd lamp was invented about 1788, more perfect apparatus became necessary, and the present excellent reflector came into use, but was preceded by a similar though smaller arrangement—Wm. Hutchinson's, as in the example shown, which is one of the earliest reflectors used.

Before proceeding to describe this optical part, a few words as to its necessity, and the object to be gained, may be said.

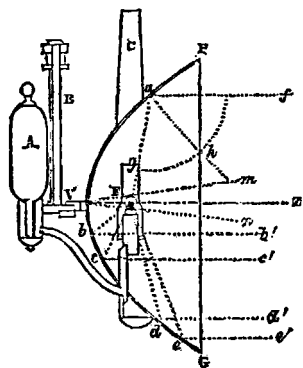


Mr. Hutchinson's Reflector, used at
Liverpool, 1763.

below would also pass away uselessly on to the ground. The object of all lighthouse apparatus is to bend these errant rays, both above and below the horizontal line into the required direction of the sea-horizon.

This is done either by a polished metal reflector behind the light, or lenses before or around the light, or by a combination of both. The first is called the catoptric or reflector system, the second the dioptric or lenticular system, the third the cata-dioptric system, which, with other modifications, is called the holophotal system.

The *Catoptric* is essentially the English system, both from its having been originated and also from its having been justly retained here more than in other countries, for reasons hereafter alluded to. The reflector is of copper, lined with highly polished silver, formed to a parabolic curve, in the focus of which is placed the lamp, which has a cylindrical flame of about 1 inch in diameter.



Section of Parabolic Reflector and
Lamp.

It is required to show a light of the most brilliant character attainable in such directions only as it shall meet the eyes of the sailor afloat,—that is only over the sea near the horizon, all other rays that may pass in other directions are lost and useless; what is wanted is only a disc of light. Now, all well know that light passing from a central flame fills a sphere as “may be familiarly proved by observing that the light of a table-lamp falls on every part of the spherical ground-glass shade.” All the rays which are thrown above a horizontal line which would divide this glass globe into two hemispheres would be lost, so that one-half the light would be wasted.

A considerable portion of that falling below would also pass away uselessly on to the ground. The object of all lighthouse apparatus is to bend these errant rays, both above and below the horizontal line into the required direction of the sea-horizon.

Its action is due to the peculiar properties of this parabolic curve. Briefly it is this, that a straight line drawn from the focus F of the parabolic curve P, V, G , to any part of the curve as F, a , will form, with the tangent to the curve at that point, an angle equal to that which a line parallel to the conjugate axis V, Z , as d, F would make on the same point. And this property belongs to every part of the parabola. So that if the line F, a , were a ray of light from a flame at F , it would be

reflected in a horizontal direction from any portion of a reflector which was formed to such a section.

If the flame were a mathematical point of light, the reflector would send forth a cylinder of rays in a horizontal direction of the diameter of its opening, but as the lamp-wick has a diameter of nearly 1 inch it subtends an angle at the vertex V of a reflector of 4 inches focal distance $F. V.$ of $14^{\circ} 22'$, the angle $m V n$. This is called the divergence of the reflector, and it spreads the light to this extent, and somewhat beyond it, for the refinements of mathematical calculation do not quite coincide with observed results. It would take 24 such reflectors to make a complete circle of light.

The Trinity House use for their lighthouses reflectors of 21 inches diameter, the sectional area of which is 346.3 square inches. For lightvessels the diameter of the reflector is 12 inches, with an area of 113 square inches, or less than one-third of the lighthouse instrument. The actual amount of the divergence of the reflected light is about 15° , but besides this there is the light of the unassisted flame which escapes outside the reflector, which has been economised in various ways as shown subsequently. As the flame has at least a surface of 1 square inch, and the parabola is adapted to a single point of light, there are many considerations as to the effect of different parts of the flame in being reflected, and very much has been argued on it, but the simple result of its acknowledged excellence is sufficient for the present. More will be said presently.

The form of reflector now in use is that calculated by Captain Huddart, an Elder Brother of the Trinity House, in 1791, and it has held its position admirably, amid all the optical changes that have passed. They are very lasting, as many of the reflectors now in use have remained unimpaired after thirty and forty years' continued service.

If there were no absorption or loss of light the effect of the 21-inch reflector, such as is exhibited, would be to increase the power of the flame about 346 times. About $\frac{1}{17}$ ths of the whole light is thrown on to it.

Much has been said in its disparagement in comparing it with its more elegant and complicated rival, the lens; but again I deferentially urge that the great loss of light stated to be $\frac{1}{100}$ ths of the incident rays, cannot be properly calculated, and these estimates must be founded on wrong premises, or the observed effects could not be accounted for. It is even said by some who are practically well acquainted with the subject, that a worn reflector, where the copper is exposed by the wear of the silver, shows nearly or quite as good a light as its more perfect neighbour.

The reflector for the floating light is only 12 inches in diameter, as in the example exhibited; larger sizes are difficult to keep horizontal, owing to the motion of the vessel, though they are carefully hung on gimbals. Its area is less than $\frac{1}{3}$ of that of the 21-inch reflector, but it has the best portion of the flame, and its divergence is much greater. It is a very great desideratum that a more powerful light should be obtained for the expensive and important position of a light ship.

For a *fixed* light, the reflectors are arranged around a circle or that part of it required to be illuminated, but not more than 14° or 15° of azimuth should be assigned to each instrument, a consideration not always fully carried out.

For a revolving light 18, 24, and even 30 of these reflectors are arranged on the faces of a revolving framework, which, by means of machinery, is made to show a face of 6, 8, or 10 reflectors in every direction at regulated intervals, producing a most brilliant light.

An intermittent light is produced by an eclipser being suddenly placed before each lamp which extinguishes the light suddenly, and by its removal, as suddenly unmasks it, giving a distinctive character from the revolving light, which gradually appears and decreases from its full brightness.

A great superiority has been claimed for the lens over the reflector, but in the enquiries made by the Royal Commission in 1858—61, although there was by no means a bias in its favour among the members, a singularly opposite result was arrived at, for out of 576 opinions of competent seamen, two reflector lights, Flamboro' revolving and the Lizard fixed lights, were preferred before all, as will be alluded to hereafter.

The present form of reflector was adopted by the Trinity House in 1788, three-quarters of a century ago, and has remained unchanged to the present day, but although it holds such a remarkably good position amid its lens competitors, I think it is by no means demonstrated that its utmost powers have been reached. A short time since I had the gratification of witnessing an experiment which convinced me of the contrary. It was made by Messrs. Wilkins, with the apparatus before the meeting, from the summit of the beacon-hill at Purfleet. The revolving frame of 4 sides carried a 12-inch reflector, a 21-inch reflector, such as is used in lighthouses, and a 36-inch reflector, the largest yet made, and which formed a prominent object in the nave of the Great Exhibition. On the fourth side was the polyzonal lens, illuminated with the 4-wick'd lamp. It was viewed from a position $3\frac{1}{2}$ miles distant. As a scale for the intensity of the lights there was, at one mile distant, several conspicuous gas lamps, and at various distances, from 100 yards to half a mile, were several other gas lamps. When the 12-inch reflector was turned on, it appeared quite as bright as the gas lamps one mile off; the 21-inch reflector showed a light more brilliant than those at half the distance, and when the 36-inch reflector was turned on (and on this point I wish particular attention), it was *brighter* than the nearest gas light.

It was unanimously considered by those present that the 36-inch reflector was as much superior to the 21-inch, as that was to the 12-inch reflector; that is, they were separated by about equal intervals. The openings of these reflectors contained an area of 113.0, 346.3 and 1017.87 square inches respectively, and they were each illuminated by an exactly similar lamp, the ordinary one-inch burner.

The great lens showed a light decidedly stronger than either, but of a different character—a whiter, more star-like appearance, precisely the difference between that of Venus or Jupiter, and of Sirius or

Arcturus. The lens light having a scintillating or radiating appearance, as a fixed star has. I know not whether this difference has been explained, though generally noticed.

The maximum divergence of the ordinary reflector is $14^{\circ} 22'$, this of 36 inches is only about $5\frac{1}{4}^{\circ}$, consequently the whole light is concentrated into a narrow arc, but sufficient to give a flash of as much or greater duration as that of the lens.

Of course, the duration of the flash from the smaller reflectors was greater than those of the other two sides, but there was assuredly no advantage on this head with the lens over the large reflector. It certainly seemed that had there been *two* such reflectors that they would have outshone the lens, which, according to some calculations, should equal 8 or 10 ordinary reflectors.

The experiment left a very strong conviction that the large reflector was a most positive and marked advance over the others, and from this I think that it is most deserving of some consideration, whether, under some circumstances, this modification of the present excellent reflector might not be introduced with very great advantage.

The Dioptric System is essentially the French system, as it was in France that it was invented, and introduced by M. Augustin Fresnel, in 1823, in which year, a fine example of the apparatus was placed in the noblest existing lighthouse, the Tour de Cordouan, at the mouth of the Gironde.

From its complete success it was made the basis for the illumination of all lighthouses, which, under the law of 1825, were systematically constructed around the shores of France. From the inventor, it is sometimes called the Fresnel system, and, under his hands, it sprang almost at once into its present completeness, as far as regards the polyzonal lens and its accessories.

There has been some needless controversy about the origin of the annular or polyzonal lens. It began with those scientific toys of last century, the burning instruments. Buffon, the French naturalist, suggested in 1773, that it should be made in three concentric rings, or cut into steps, which was acted on by the Abbé Rochon in 1780; this lens, and one afterwards made by Messrs. Cookson, of Newcastle, were probably the only ones made by this most troublesome process. These inventions are alluded to in most of the works on burning instruments of the period. The next step was the proposition of Sir David Brewster, who, in 1812, for the same purpose, suggested that it should be built up of separate pieces. No mention is made at this time of its converse properties, that of distributing light. Lighthouses at that period had not attained sufficient importance to interest the world at large, and the excellent reflectors in use were considered to do their work perfectly.

The first proposal to use glass to control the light, is that recorded by Smeaton, in 1759, when a London optician proposed to grind the panes of the Eddystone lightroom into segments of a sphere. The statement is obscure, but the suggestion was not acted on. William Hutchinson, who first made reflectors at Liverpool in 1763 and 1765, is also an early claimant for the lens. He tried a hollow lens filled with brine,

but it broke with the heat of the lamp. The earliest *real* use of lenses was in one of the Portland lighthouses, where they were put up by Thomas Rogers, somewhere between 1786 and 1790. These lenses were 21 inches in diameter, and $5\frac{1}{2}$ inches thick in the middle. Behind the flame of the lamp placed in their focus, and which was 3 inches in diameter, were placed his patent (spherical) silvered glass reflectors, 12 or 18 inches in diameter. These were covered without the use of quicksilver, and threw back the image of the flame, through the focus, on to the lens, thus shadowing forth the new holophotal system of the present day, as will be presently explained.

Similar lenses were placed by Rogers at the lighthouses at the Hill of Howth, Waterford, and also at the North Foreland, Kent, where they remained till the establishment was alienated from Greenwich Hospital, and came to the Trinity House in 1834. There were 15 of them, most carefully worked, 16 or 18 inches in diameter, and costing £50 each. They were also aided by the reflector behind the lamp.

These heavy lenses naturally absorbed much light, from their great thickness, but the intention was good, and their use demonstrates that much study had been given in these early times to lighting, when lighthouses were held rather as sources of profit than in estimation as useful sea-marks.

But all these adaptations of glass were inferior to the silvered reflector, and there is no question that their improvement and farther introduction into this country was impeded and retarded in later times by the difficulties that the excise duties and restrictions, placed on the large masses of glass required in their manufacture.

Augustin Fresnel invented the annular or polyzonal lens, or brought it into actual operation. The first occasion was in the autumn of 1821, during the progress of the Great Trigonometrical Survey of France, when one of 3 feet in diameter was shown across the channel from Cape Grisnez. Major Colby observed on this side, and he communicated the circumstance to Mr. Robert Stevenson, of Edinburgh, in November, 1821, and on July 23, 1823, a splendid apparatus was put up at Cordouan.

Prior to this there were but very few lighthouses, except in England; not more than seventeen or eighteen principal lights on the Atlantic coast of France, and from this date, as before stated, a complete system was adopted from the scheme drawn up by the French hydrographer, Admiral Rossel; and the new apparatus was alone to be used in all new lighthouses.

It is to this circumstance,—the French system being established at once,—that comparisons have been made in disparagement of our system, which, to a great extent, was in existence at the time, and had grown up with the requirements of an increasing commerce, or as means were obtained for the erection of lighthouses.

The dioptric system is dependent on the refractive properties of glass, which although generally well understood, I may be pardoned for briefly adverting to. When a ray of light passes obliquely from one transparent medium into another of different density, as from air into water or glass, it assumes a different direction at the common

surfaces of these two planes; a fact which is familiar to all in the appearance of a straight rod, an oar, or a mooring, when it dips beneath the water. At the surface it suddenly appears bent or broken (refracted) into a new direction beneath it. The same occurs with a ray of light through glass; and when it emerges from the other surface of the glass its direction is again changed. This change of direction, or the angle which the two directions make, varies with the density of the glass, &c., and that which it makes with a normal or perpendicular, is called the "index" of refraction. If the two surfaces of the glass are parallel, the issuing ray is in the same direction as the incident ray, the intermediate portion passing through the glass at a different angle.

If the two sides of the glass are *not* parallel the issuing ray will assume a direction relative to that surface and the air beyond it, and the light will pass in the three directions. The object of a lens is therefore so to arrange its two surfaces, that the ray it receives on one surface shall pass through the substance of the glass to the opposite surface, which latter is made at such an angle that the ray shall emerge in the direction required. This is a matter for rigid mathematical calculation dependent on the refractive index of the glass.

As a lighthouse lens is intended to deliver the rays which it receives from the focal lamp, at oblique angles, always in a horizontal direction, a plano-convex form is always chosen, both for the greater ease in working it, and for the purpose of more readily correcting, in these large figures, the aberration for sphericity. Other optical qualities are disregarded, such as the chromatic aberration, as the light to be dealt with is not a minute point, which would render greater attention necessary to these points, and as will be seen presently when the electric light is shown through one. As the flame is of considerable dimensions, its area neutralizes these difficulties.

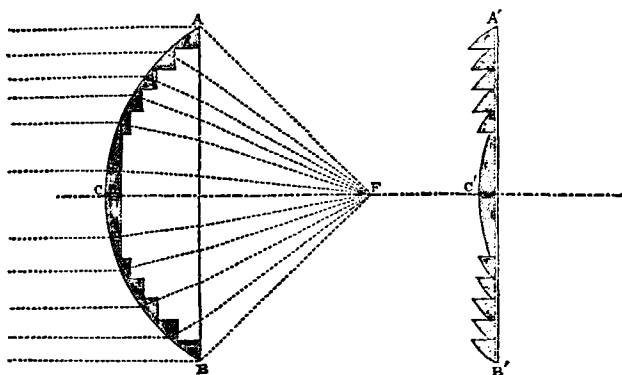
The plano-convex lens then is applied with the convex side away from the focal lamp, and the incident rays from that focus are refracted in the body of the lens, and finally pass out horizontally as required.

The converse of this is more familiar by the parallel rays of vision or of the sun, passing on to the convex side and centralizing in the focus, either magnifying it to the sight, or burning it by the sun's rays.

The annular or polyzonal lens acts in precisely a similar manner, and is formed on the following principle:—

The size of the lens being determined on, and its focal distance being also fixed, the normal form is assumed, as if it were to be a solid mass; but as the action of such a lens is due to the relative directions of its two faces, without reference to the thickness of the intervening glass, the convex surface of the lens may be supposed to be cut into concentric rings around a central disc *C*; *ABC* is a section of an ordinary plano-convex lens, whose focus is at *F*. As the great thickness of the central portion abstracts much of the light in its passage, the convex surface may be supposed to be cut into circular zones, whose section is as the shaded part of the diagram, and these

sections being all placed in one plane, as $A' B' C'$, the latter will have all the optical properties of the former, because the two surfaces are still of the same relative figure.



The annular lens can be built up to any convenient size, or made into the square figure of the example exhibited, for which I am indebted, as for the other apparatus, to Messrs. Wilkins and Son, who have done so much for lighthouse engineering.

The calculations for the curvature of these rings are necessarily abstruse; the methods of grinding and numerous other interesting features of their construction cannot be entered into here.

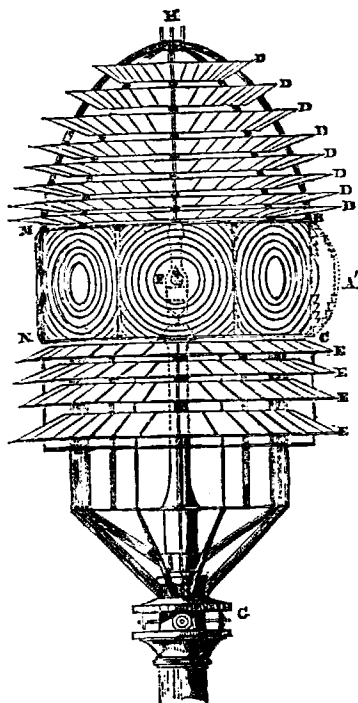
This lens is adapted for a first order apparatus, it is of 36.22 inches focal length; has an area of about 1,300 square inches; weighs about 1 hundred weight; and costs £60.

This lens is only adapted to a *revolving light*. Eight of them are built into an octangular prism, M, B, N, C , around the focal lamp F , and this is made to revolve by regulated machinery. The effect to a distant observer is a brilliant flash, of the size of the lens, each time that one passes before his line of vision. The brilliancy of this flash, according to some calculations, is equal to that of 3,000 unassisted Argand flames. By other estimates it is made somewhat lower.

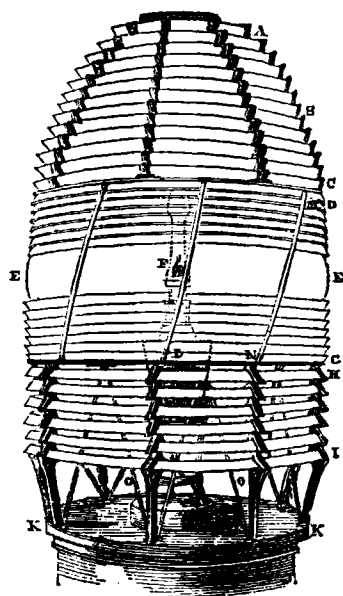
This portion of the apparatus only embraces an angle of about 46° , or rather more than one-fourth of the entire light. The rest is economised on a different principle, as will be presently shown.

For a *fixed dioptric light*, a different modification of the same principle is used. Instead of the central portion being made up of annular lenses, it is a cylindrical belt, of the section C, D, E , similar to that of the lens, made to revolve around the focus F in a perpendicular direction. The effect of this central belt $E E$ is, not to distribute the light into eight beams, but equally all round the compass—that is, from whatever direction it is viewed a bright band of light, of the breadth of the flame F from the lamp L , is visible from top to the bottom of the central belt.

In the first instance this apparatus was made a polygon of 32 sides,



View of a first order *revolving* Dioptric Light, with upper and lower *reflecting* Zones.



View of a first order *fixed* Dioptric Light, with upper and lower *refracting* Zones.

but in 1836 Messrs. Cookson made one entire, which was the greatest step then achieved.

In the separate panels of which the central belt is made up, the sides are not perpendicular, but diagonal, M, N; forming them into rhomboids, in order that the metal framework which holds them together, should not obstruct the band of light throughout their whole length, in any one direction.

For the remainder of the light, which passes over and under the central zone, different means have been applied to economise it. In the first apparatus, the revolving light of Cordouan, and in similar apparatus at the Skerryvore, a complicated arrangement of eight smaller lenses are placed over the principal lenses, in a conical form. These throw the light diagonally upward, and it is then received on to eight long plane mirrors, diverging outwards and upwards from the centre of the apparatus, and which reflect the bright images of these eight smaller lenses into a horizontal direction, adding their power to that of the central lenses. This form of apparatus, though beautiful and effective, is not now much used.

Another form of upper and lower zones was also at first used, but in new apparatus is abandoned. It consists of a series of rings diminishing in size above the apparatus; to which were attached a large number of plane mirrors, formed of looking glass, which *reflected* the image of the flame thrown on to them in a horizontal direction. The same system was applied below the central zone. (See D, D, E, E, in diagram on p. 231.) Strictly speaking, these ought to have each formed a portion of a parabolic curve, suited to the focal lamp, but the size of the flame rendered this refinement of less consequence.

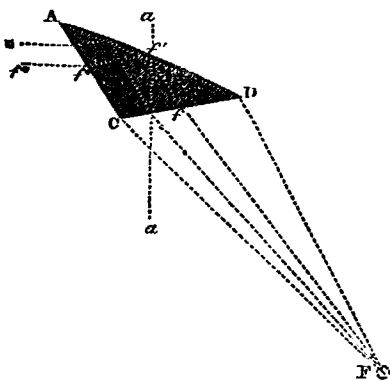
In the outset of the dioptric system, the smaller apparatus, and at a later period in the largest apparatus, a much more beautiful and effective plan was introduced for these supplementary zones. The first, on a large scale, were the lower zones of the Skerryvore light, by Alan Stevenson, since which they have become universal.

These are totally-reflecting-cata-dioptric prismatic zones—a long array of words, which however are expressive; the particular action of which may be explained by a very familiar experiment.

Place a stick of sealing wax, a pencil, or any other substance, in a sloping direction from you in a tumbler of water. Raise the tumbler above the level of the eye, until, at a *certain angle*, you will see the image of the sealing-wax, &c., *totally reflected* under the *upper* surface of the water.

Importing the principle thus demonstrated into the lighthouse service, these zones act as may be thus explained. In the diagram representing a section of a zone, A, D, C, which is so placed in regard to the focus F that a ray falling from it at *f* will be so refracted on to the side D A at *f'*, that, instead of passing out, it will be *totally reflected* (as in the tumbler of water) at that point of incidence *f''*, into the direction *f'''*, and finally pass out in the required direction. This angle *f f' f''* is less than $41^{\circ} 49'$, as with more than this it would not be reflected, but pass out upwards.

This beautiful optical arrangement is well exemplified in the apparatus before the meeting.



In a first order light there are eighteen of these zones above the central belt, and eight below it; the entire apparatus forming a most beautiful object 10 feet high and 6 feet in diameter, a view of which has been previously given, costing, for the optical portion only, about 1,300*l*. The public were familiarised for the first time with it at the Exhibition of 1851, and the much more beautiful series shown in the nave of that of 1862, especially that by the Messrs. Chance, gained universal admiration.

The dioptric apparatus is divided by the French into six orders or

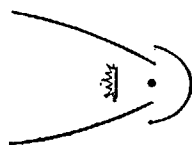
sizes ; from the powerful first order, 10 feet in height to the small harbour lens of $11\frac{3}{4}$ inches in diameter.

Thus far have we explained the apparatus for the revolving light, with its eight lenses, and that for the fixed light ; but there is another appearance not used in the English lights, but which is largely applied in France and elsewhere. It is termed the "*Feu fixe varié par des éclats.*" A fixed light, varied by flashes, preceded and followed by short eclipses. This appearance is obtained in various manners under the original dioptric arrangement ; one of the most usual of which was to make two or three panels of vertical lenses revolve around the fixed horizontal apparatus ; thus collecting all the beams which fell on them into one ray of the breadth of its face. It is now managed in a different manner. The apparatus is formed of alternate panels of fixed and revolving elements, or of central zones and annular lenses, which, when the entire apparatus is made to revolve, will produce the appearance in question. These brighter flashes generally appear at long intervals of 3 or 4 minutes ; and it has been objected that under difficulties of bad weather, or want of close watching, that the flash might not be seen, and the light mistaken for an ordinary fixed light, which it otherwise resembles. Sometimes this flash is coloured red, and, but rarely, green.

Up to a recent period the lens manufacture was exclusively held by the French (with the exception of Messrs. Cookson) from the superiority of their glass ; and this advantage, maintained by our fiscal regulations, led to the construction of a large portion of our light-house apparatus, by MM. Soleil, François, Letourneau, Sautter, &c., in Paris. Later, however, our country has had the advantage of the enterprize of the Messrs. Chance, of Birmingham, who, aided by the scientific attainments of Mr. James Chance, have placed some of the finest examples in the world in our recent lighthouses, and also have reached a perfection leaving little to be hoped for.

Hitherto, the remarks have applied to the apparatus as originally employed, in which there is still some loss of light in certain directions, both in the lens and reflector. This consideration has led Mr. Thomas Stevenson, one of that family to whom practical pharology is so much indebted, to propose some arrangements which he has termed the holophotal system, from two Greek words signifying "whole light."

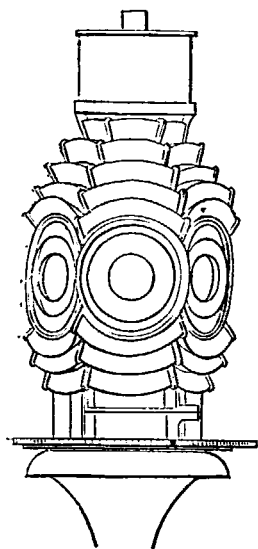
The ordinary reflector is made holophotal by cutting off the part behind the focus, and substituting a hemispherical reflector behind the flame, in front of which, and in that area which is not controlled by the parabola, a small lens, the action of which combination will be understood by the diagram.



In the apparatus before the meeting, a "direction-light," also kindly furnished by Messrs. Wilkins, and which stood in the nave of the International Exhibition, is an example of the first application by Mr. Thomas Stevenson of his system. He proposed it in 1849, and the Horsburgh lighthouse, in the Strait of Singapore, has nine such

reflectors for its revolving light. The diagram will show that *all* the light is economised. It consists of a spherical reflector behind the light, which throws all the posterior rays on to the combination of annular lens and prisms in front of it.

Some approach to this arrangement was made by Mr. Gordon, in 1817, and also by Thomas Rogers, in 1793, as before stated.



Holophotal revolving Lens.

In revolving lights all the rays are thrown into the beam of the great central lens, by making the upper and lower reflecting prisms of a corresponding curve, as in the apparatus exhibited, thus increasing the power of the flash, but making the intervals nearly dark, as the whole surface of each lens is luminous when presented during its revolution, and no light passes at the angles.

This subject might be pursued to a very great length with the variety of plans suggested and in operation, but time will not allow of it.

The Flame.—All are familiar with the cylindrical wick'd lamp; by means of which both sides of the flame are exposed to the current of air necessary for combustion. This was not invented (by Argand, a citizen of Geneva), till 1780 or 1785, and then it was almost accidental. He had been vainly trying to make the air ascend through his tubular wick, when his brother unintentionally placed a broken bottle neck over the flame, when it shot up into a brilliancy that sent Argand into raptures, and by its immediate introduction in general use, must have had a most important bearing upon the social condition of the world at large. For it is difficult to conceive how our ancestors, before this, pursued their avocations by the light of the miserable torch-like lamps, or the smoking candles then only attainable. Argand's lamp was perfected at once, and now is exactly as he left it. It is used in all reflector-lights, with a wick $\frac{7}{8}$ ths inch in diameter.

For the great dioptric lights a different modification is used. It is a complicated mechanical lamp (when of the best form) with four concentric wicks; the outer one 3.39 inches in diameter, the inner one $\frac{8}{16}$ ths of an inch. The great heat from this lamp would char the wick, if means were not employed to keep it abundantly supplied with oil, which is effected by four small pumps, kept in action by clock-work, which causes the oil to flow over the wicks much faster than it is consumed; after which it is filtered and returned to the reservoir. For the smaller apparatus, lamps with three or two concentric wicks are used.

The quantity of oil consumed in the 1-inch burner *ought to be* about 48 or 50 gallons per annum, and in the great Fresnel lamp of four

wicks, about 750 gallons per annum; for it must be remembered, that the quantity of oil properly burnt, is an exact index to the amount of light produced. It is most essential that the flames should be kept of a proper height, or much power is lost, and the upper part of the flame is, in each case, that which falls upon the sea.

Gas, with but few exceptions, is not used for lighthouses, though a most desirable light, both from its brightness and the power of producing a flame of any dimensions, but from its nature, it is inapplicable to situations where it cannot be properly produced.

Colza oil is now the fuel used in our lighthouses. It has been so since 1846, prior to which the best sperm oil was alone used. The change is fortunate, for the industry of the American Whalers has nearly destroyed the source of that oil. Colza oil is made from the seed of the colza or colzat, a species of wild cabbage now extensively cultivated for the purpose in Normandy, &c., and is a very excellent, a superior substitute, for its expensive predecessor.

A brighter flame than that now used, but of equal dimensions, is a very great desideratum, but it has not yet been satisfactorily obtained. Whether any modification of the lamps burning the new petroleum, or other mineral oils, could be brought to bear, I know not—the direction is worth trying.

An improved flame would have a most important bearing on the system, for a small per centage of increased brightness, would more than outweigh all the contrivances which have been made to economise it, and it would be multiplied to a large extent by the optical arrangements; and now that lighthouses are in competition, as it were, with passing ships, each with its lights, frequently excellent, it has become a still greater want.

One proposition by Mr. Gurney, in 1835, of impinging oxygen gas on the flame had the desired effect of vastly increasing its intensity, but could not be carried into practical use, and we are met at once with the difficulty of procuring and storing the gas.

The same obstacle also intervenes with another splendid light, that first proposed by Lieutenant Drummond, 35 years since, and which was then largely experimented on—the lime light. It could not be made to act with certainty and steadiness, an imperative necessity with lighthouse purposes. A modification by Mr. Renton obviates some of the difficulties by enclosing the lime cylinder in a wire cage, which prevents its cracking and breaking off, but I believe there are great difficulties in placing it in a lighthouse, one of which is, the want of oxygen gas.

We come now to another light, which in one instance only has become a part of our lighthouse system—the magneto-electric light—now permanently established at Dungeness. This is the first real step in the very important point of increased illumination, and in the almost equally important particular, of a different character of light.

This light which was in operation in the Great Exhibition of 1862, was certainly the greatest wonder that that world of marvels con-

tained, and a feeling of awe arose at the contemplation of a machine, that of itself, gathered together, from separate masses of quiescent iron, that mysterious agency, or power, or force inexplicable, by which nature's processes are carried on, and by which our very life and actions are maintained, and made it manifest to the sense in light as glorious as the sun itself. The whole process is a marvellous illustration of that correlation of each physical force in nature's workings—an evidence that one power may be traced throughout a train of operations until it emanates in a totally different form, and yet that all these phases of action are identical.

It is to the talents and assiduity of Professor T. H. Holmes, that this extraordinary machine is owing. I am sure that it must have cost years of labour and thought to solve the problem of a continuous and equable current of electricity, or magnetism, for by their action in this they are shown to be identical. All previous attempts were made by the action of the galvanic battery, which, as is well known, cannot well be maintained at a constant state of power.

Briefly, the action of the magneto-electric machine is this. A triple series of permanent soft iron magnets, arranged in a circle, are made to give off their influence to a series of electro-magnets attached to a revolving wheel, from which it passes to the lamp as a single current, and then through the minute space between two carbon-pencils, where it shows, not a flame nor incandescence, but a light of the most intense brilliancy, not more than $\frac{1}{8}$ or $\frac{1}{16}$ of an inch in cubical dimensions.*

It was in successful operation in one of the South Foreland light-houses for nine months of the year 1859, and since June of last year has been in constant use in the Dungeness lighthouse, and is, therefore, essentially a part of our lighthouse system.

It is difficult to estimate the intensity of this light, but I have heard that, viewed from the Varne lightvessel, midway between it and the Grisnez revolving light (one of the best of the French lights), the *fixed* electric light equals, or exceeds, the brightest flash of the Grisnez light, which is eight times as strong as the fixed light would be. Again, an experiment was made with it, and the reflectors still remaining at Dungeness. They were shown alone, and were distinctly visible from the distant station. The electric light was then shown in addition, by which, of course, the strength of the lights was immensely increased. The oil-lamps were then extinguished, and not the slightest decrease of power was observed; so that all the previous light made no perceptible addition to its power.

One most important feature is the entirely distinct character of the light, it cannot be mistaken for any other light; and this fact gives a great power of multiplying our lights without causing confusion. And it may now be applied most usefully by superseding some of the

* Mr. Holmes subsequently explained the operation of his lamp, which was acted on by the galvanic battery instead of the appropriate magneto-electric machine above-mentioned.—A. G. F.

existing lights where there are greater necessities for having a well-marked starting-point.

It may be urged that it would be difficult to place it in many of the isolated stations, such as the Bishop Rock, or the Eddystone, from the difficulty of finding a place for the necessary steam-engine to drive it. I would venture to suggest that there is a power at hand, ready to be impressed in this service, in the ceaseless action of the waves and tide. A series of levers acted on by this force, might be made either to pump water to an upper story, or to raise weights, which, by their descent, would give the necessary motive power.

For a floating light, which most of all requires improved illumination, there is the constant tug at her moorings, which might be applied to a series of springs or accumulators, by which their power might be husbanded for the same purpose.

Reverting to the question of lightvessels, to which, if the electric light can be applied, will give them a vastly increased importance, it may be said that the dioptric apparatus is not applicable. Their constant and irregular motion defies all efforts to produce that stability necessary to the action of such optical apparatus, and although the Trinity lightships have been universally praised, as far as they go, still an advance, as I think with others, can be made.

Mr. Herbert's proposed form of floating-vessel has been found to act exceedingly well in many places, and at Liverpool it is, I believe, exclusively used in that important port for the large floating beacons. They are circular and are moored from their centre of gravity, or near the surface of the water as shown in the section; and the effect of the form and mooring is such that no other floating body possesses such stability. In evidence of this, a bell-beacon on this principle was moored off the entrance of the Queen's Channel, and its motion was so slight that it would not ring the bell at the top of the shaft that rose from it. Such a floating vessel would be excellently adapted for the electric light, as it could accumulate the necessary power either from its mooring, or from the passing of the tide.

Mr. Herbert's proposition to use these floating lights was a grand one. It was to moor a line of them along the fairway of the English and St. George's Channels, in the former at each degree of longitude; so that by their means vessels might avoid the dangerous proximity of the coasts, and yet be perfectly assured of their situation, which is the only object often gained by closing with the land. This scheme is of daily increasing importance from the increase of steam-vessels, and of that gigantic evil, collisions at-sea. The proposal is, that all vessels going down channel should keep to the north of this line of lightvessels, and those coming up to the southward of it, thus almost annihilating the chances of falling foul of each other, and which, with the use of steam, would render it a matter of no difficulty. There are numerous other features connected with it which I regret that time will not allow me to dilate on here. Respecting its practicability, till it is pronounced not to be so by ample experiment, we may feel assured that the engineering skill which has surmounted much greater apparent difficulties than this, could readily accomplish what many deem a most important result.

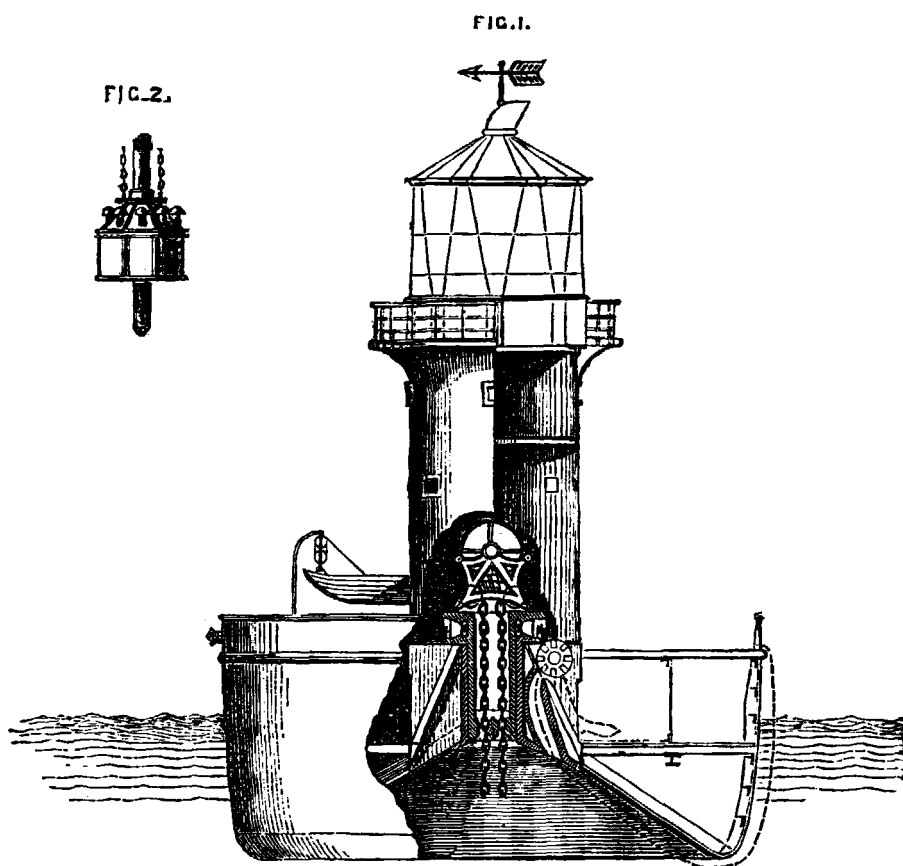


Fig. 1.—Mr. Geo. Herbert's proposed Floating Light.

Fig. 2.—Ordinary Lightvessel Lantern on the same scale.

General Remarks.—There are some points in the economy of lighthouses which have been, and perhaps are still, the subjects of controversy, of misunderstanding, and even of misrepresentation. As was said before, there are few works extant on the subject, and these have been drawn up from a point of view which has somewhat of a tendency to elevate the dioptric principle in its comparison with the reflector, and in this, some positions have been advanced which I respectfully deem to be fallacious. It has been said that a large proportion of the light—even one-half and more—is lost by absorption in a metal reflector, and that for this, and other reasons, the lens is from $2\frac{1}{2}$ to 4 times as advantageous as the reflector. Upon this

assumption it has been asserted that our Trinity House, as the guardian of our coast-lights, have failed in their duty in retaining the reflector, when a better system was introduced.

Going much farther than this, it has been broadly stated that our country will bear no comparison with others as regards the lighting and buoys of its coasts. These opinions, held in high quarters, led to the appointment of a Royal Commission in December, 1858, which, in the 2½ years it occupied, made a most rigid investigation of the subject (omitting, however, some very important points). The voluminous Report of this commission, if it has added little to our previous knowledge, has at least brought forward many testimonies at variance with the assertion and spirit which led to its appointment.

I said, in 1847, when but little was generally known of lighthouses, and less had been written, that if our English lights were so inferior to the French (the former being reflector, the latter lens lights), every sailor in beating up the English Channel was able to judge for himself, as he came in sight of each coast alternately, and would most assuredly have availed himself of the Englishmen's privilege, to grumble at what he was told he was paying very dearly for, if our lights had any inferiority. But no such complaints were ever recorded. From 1858-60, the opinions of 576 mariners were collected by the Royal Commission, and as it is for this class alone that the lights burn, their evidence outweighs all other. To the question "what British light have you seen farthest off?" the following are the number of replies in favour of each. *Reflector*, revolving, 260; intermittent, 29; fixed, 90. *Dioptric*, revolving, 85; flashing, 56; fixed, 9. So that 260 mariners have named 10 first-order *reflector* lights (there are only 13), while out of 10 lens lights, only *two* are named.

This, I think, most conclusively settles the question as to the propriety of retaining the reflector. It is a very remarkable circumstance, that the two most generally named, are the Flamborough revolving, and the Lizard fixed light, the latter of which theoretically would be far inferior to its rival, the lenticular fixed light.

Carrying the comparison a little further—that is, between the British lights and those of the rest of the world—by referring to the Report, we find that:—

Of 715 mariners only 17 think our coasts *not* well lighted; of 586 mariners 8 think our coasts not so well lighted as some other countries, while not one foreign witness prefers the lighting of any foreign shore.

This is as to the *quality* of the British lights. Now for a few remarks as to their quantity. In the Report—France, being taken as a standard, has one light for every 12·3 miles of her coast.

England (whose 41 very important floating lights are excluded) has one for every 14 miles; but if the lightvessels are added (as they ought to be), it excels France, for the unit is 11·37 miles.

Ireland is said to have only one light to 34·5 miles, and this curious result is arrived at by measuring the distance between them around the sinuosities of the intricate coast which separates them.

Scotland, by the same geographical process, has only 1 light to 33·5

miles of coast, or, as it is said in the Report, "France is more than three times" as well illuminated as Scotland or Ireland

Now, I would appeal to the chart of the lighthouses of the most important commercial part of Europe, as recently prepared for the Trinity House, which I have the honour of laying before the meeting, to demonstrate that these figures, and the inferences they might induce, are absolutely erroneous.

The western and very intricate coasts of Scotland, which are made to swell the mileage, and reduce the average of its lighthouses, has neither ports, shipping, commerce, nor products; and, what is of more consequence to the present question, it has no shipwrecks. Had these coasts been measured on the same system as the straight French coasts have been, Scotland or Ireland would be shown to be as well guarded by night as any other country.

The lenticular system, in its various forms and arrangements, may be pronounced to be nearly perfect. The next source of improvement may be taken for the flame itself, which now outweighs all other points, and is deserving of much consideration. The character of the light, as in the electric or lime light, I strongly urge is of the greatest importance. With respect to the reflector, I have pointed out what I think is a direction for further trial. Many other points might be here brought forward if time permitted, but what has been said must suffice. The system is deserving of much consideration for the many beautiful adaptations of refined science which are in use.

The Trinity Corporation, the guardian and chief director of the lighthouse system, I have been explaining is one of the very few, if it be not the only one, that has come down to us from the middle ages (for it dates from temp. Henry VII.), occupied the most honourable and useful field it has so well filled, and for which it was instituted. Those who have any veneration for the past history of our country in its better phases, must desire to have that transmitted to posterity, which in the past and in our own times has proved of such immense benefit to the world at large.

I have thus most briefly alluded to the main features of the subject, leaving many others of great importance untouched for want of time and consideration for your patience. But I cannot conclude without thanking the Messrs. Wilkins and those gentlemen who have enabled me to illustrate what I have said, with the beautiful and costly apparatus before you.

MR. FENDLAY: In reply to a question as to the achromatising the lenses, I should say that I only just alluded to it, as in practice the correction for the chromatic aberration is disregarded. The annular lens exhibited is adapted for a flame of 3 or 4 inches cube, which neutralises all the effect. But when a minute point of light, such as the electric light, which is not $\frac{1}{4}$ of an inch in diameter, is placed in its focus, this aberration becomes very manifest in the beautiful coloured rings it displays. Such a light requires a special lens.

The electric-lamp exhibited is that of Professor Holmes, and is the same instrument as was shown from the summit of the Monument at the recent illuminations. But it is not lighted now by the means to which it is adapted. It is now in action by means of a powerful galvanic battery of the ordinary form. Its proper apparatus is the magneto-electric machine, such as that shown in the Great Exhibition, which perhaps Professor Holmes will presently explain.

The CHAIRMAN : Professor Holmes will perhaps explain his electric lamp.

Professor HOLMES : To produce a constant electric light, it is requisite that the carbon points should be maintained separated to a distance proportional to the strength of the current ; but, in order to light the lamp, the points must be brought in contact for an instant, because the current of electricity produced by a galvanic battery, or a magneto-electric machine, will not pass through space—in other words, has no “striking distance,” as it is termed. On separating the carbons, however, the current continues to pass—which, at the first blush, seems to contradict the statement I have this moment made, that it will not pass through space ; but this is explained by the fact, that the intense heat generated by the electric current liquefies a portion of the carbon, and that the current passes from one carbon point to another, not through empty space, but through the carbon thus liquefied. This lamp before you is now placed in connection with the galvanic battery, but, as you perceive, there is no light. I now bring the points in contact, and I beg you to observe that the moment they touch, the light is produced in its full intensity ; but if the carbon points remained in contact, no light would be produced ; the current would then pass from the point of the upper to that of the lower carbon, as it does through the bodies of the carbons themselves, without giving any light ; therefore, you may conclude that the lamp has, by some contrivance in its construction, separated the carbons the instant they touched. This contrivance exists, and I shall explain it presently ; but I may here remark that this function of the lamp is of paramount importance, for, without it, should the light be extinguished, by diverting the current for an instant, the points would run together, and remain in contact, when, as I observed before, no light would be produced, until the lightkeeper in the lighthouse himself separated the points by hand. Having put this part of the lamp out of action, and allowed the points to run together, you perceive there is no light until I separate them by hand. I now however allow that part of the lamp to act freely, and again extinguish it in the same manner as before, that is by diverting the current. You perceive that so quickly does the light re-appear that I deem it necessary to repeat the operation in order that you may be quite assured that it was really put out. Having thus shown you the peculiar action of this lamp, I will proceed to explain its construction, and the principles therein involved. Two cords are wound in opposite directions upon a compound spindle of different diameters ; these cords, by means of pulleys, when the spindle is turning in one direction, will be wound on the small diameter, causing the lower carbon-holder to rise, and will be unwound on the larger diameter of the spindle, causing the upper carbon-holder to descend with double the velocity that the lower carbon ascends. That being the ratio of the combustion of the two carbons, the luminous point is maintained constantly in the focal plane. But it is nearly impossible to obtain carbons of equal hardness ; hence, though the ratio in the movement of the lamp is adjusted to the ordinary ratio of combustion, still cases may occur where the upper carbon, say, may be harder or softer than usual. In the first case, the luminous point would descend below the focal plane ; in the second, would ascend above it. This is the only circumstance that renders necessary the attention of the lightkeeper during the combustion of a pair of carbons. A short time after lighting up one pair of carbons, the keeper observes whether the luminous point maintains its position : this he does, not by looking at the light, which, in such close proximity, would be injurious to his eyesight, but by noticing the position of the rays on the frame of the lantern, where two black lines are marked so as to enable him to judge instantly whether the luminous point is ascending or descending. Whichever it may be, the light is brought back to the focal plane by simply turning this button to the right or to the left—to the right, lowering the points, to the left elevating them. The manner in which this is done may be thus explained. What may be termed the fixed end of the cord connected with the lower carbon, is wound on a small spindle terminating in this button ; by turning it to the right, this cord is unwound, and the lower carbon descends, and is followed by the other carbon ; by turning it to the left the cord is wound on this spindle and the lower carbon is elevated, but as this will not elevate the upper carbon this is generally done slowly, so as to follow the upper carbon as it burns away. An expert hand will turn the two at once, and do it in an instant. This, as I have ob-

served, is the only point to which the attention of the lightkeeper is necessary; but, after two or three months' practice, a lightkeeper will pick out for use pairs of carbons of equal hardness, which will maintain their exact position in the focal plane, and need no manipulation. I now bring my remarks back to the movement of the carbons. You will observe that, by winding up the lamp, I separate the carbons several inches, and in removing my hand, the carbons, as you perceive, run together with considerable velocity. (No spring is employed for this movement,—the weight of this tube which carries the upper carbon, in unwinding its cord causes the spindle to revolve and wind the cord of the lower carbon on the smaller diameter). This rapid approximation would continue until the carbon points touched, and unless obviated by mechanical contrivance, the carbon points would always be in contact, and no light could be produced. To prevent this, and maintain the carbons at their proper distance, an electro-magnet is employed with a lever, balanced on a fine steel fulcrum and placed over the end of the electro-magnet, carrying an adjustable piece of soft iron opposite the end of the electro-magnet. This lever is about six inches in length, and the fulcrum is an inch and a half from one end. To the short end of the lever is attached a spiral spring, capable of being strengthened or weakened by turning this button right or left; the other end of the lever carries a catch, pointing downwards, similar to the tooth of a wheel. On the end of the spindle, on which the cords are wound, is a toothed wheel about six inches in diameter which revolves with the spindle; this wheel takes in to a pinion fixed on another small spindle, on which spindle, immediately under the lever, is fixed a small wheel composed of a boss, into which are inserted twelve pieces of steel wire about two inches long, each placed like capstan bars; the outer points of these wires being all bevelled off on one side. The use of the lever is as follows:—The electricity, before passing to the upper carbon, has to pass through the wire wound on the electro-magnet already mentioned. The strength of this magnet is proportional to the quantity of electricity passing through the wire, and the quantity of electricity passing is again proportional to the distance between the carbon points,—therefore, the strength or attractive power of the electro-magnet is proportional to the distance between the carbon points. Now, to regulate the lamp for a given current, and a given distance between the points, all that is necessary is, in the first place, to adjust the piece of soft iron carried by the lever to such a distance from the end of the electro-magnet that the force exerted on it to draw it down should be somewhat proportioned to the strength of the spring attached to the short end of the lever. This is what I term adjusting the lamp for a given current; and when once done, requires no further adjustment for small variations in the current. Now, I must ask you again to follow me through the motion of the lamp to realise its working with more perfect exactitude. The descent of the upper carbon causes the main spindle to revolve; the large wheel fixed to this causes the second spindle to revolve through the pinion into which it is geared; thus the star or capstan-wheel is caused to revolve with twenty-four times the velocity that the main spindle revolves; but when the current is passing, the electro-magnet attracts the iron fixed in the lever, thereby drawing down the lever to a distance regulated by set screws, such that the tooth or catch at the long end of the lever catches one of the bars or wires of the star-wheel, and thus prevents all motion in the lamp. The stud or button that acts on the spiral spring at the short end of the lever is turned so as to strengthen the spring sufficiently, that when the carbons are at their proper distance asunder, the strength of the spring which tends to lift the lever, and the strength of the current round the electro-magnet, shall exactly balance one another. Then, as you can readily imagine, the slightest increase of distance between the carbons will give the preponderance to the force of the spring, the lever is lifted by it, and the carbons approach; but the moment the carbons approach by the smallest distance nearer to one another than the balancing distance to which the lamp was regulated, the electro-magnet is more powerful than the spring, draws down the lever, and stops the approach of the carbons. This action is being continually repeated during the whole period of the combustion of the carbons,—each approachment of the carbons being but the four-hundredth of an inch, a variation so small that the distance between the carbon points may be said to be uniform: and as every variation in the distance between the carbon points causes

a difference in the amount and colour of the light, this uniformity of distance attained in the present lamp is the cause of the steady and uniform light which it produces, and which you now observe. I must now pass to the second part of the mechanism of this lamp—that is, the part which causes the instantaneous separation of the carbon points on their coming in contact. A second electro-magnet is employed for this purpose, placed under one end of a lever whose fulcrum is in the centre; to this end is suspended a small piece of soft iron, within about an eighth of an inch over the end of the electro-magnet; to the other end of this lever is fastened the fixed end of the cord passing through the pulleys of the upper carbon-holder. Now, when the current is not passing, the piece of soft iron is, as I have just remarked, about an eighth of an inch from the end of the electro-magnet. The moment the carbon points touch, the current causes the piece of soft iron to be instantly attracted, drawing down that end of the lever, elevating the other, and with it the tube carrying the upper carbon to the extent of half that distance, or one-sixteenth of an inch, owing to the double pulleys. There is a bolt here, which, if I push in, stops the action of this lever; and here also is another one which, on being pushed in, stops the movement of the clock-work. You see I put the light out simply by pushing in this first bolt, and diverting the current for an instant. If I had not shut that it would light again. The operator can maintain the points of the carbon at any distance he requires. But you have heard of arcs of light, four inches, three inches, two inches, in length; why do I burn it the one-sixteenth of an inch? Every piece of apparatus in a lighthouse has a focus, or ought to have. If I have two luminous points (and two ends of carbon would be two luminous points), and if they were one inch asunder, I should have them half an inch out of focus. Again, the further they are apart, the more coloured is the light. The object is to have light as much like sunlight as possible. In ascending the stairs of Dungeness lighthouse,—where the Magneto-electric Light is in operation,—it is a most extraordinary thing to observe the light; it always appears as if it was the dawn of day; it never looks like gaslight.

Another thing in this lamp is its absolute steadiness, although every current requires a little regulating. At present this is over-regulated, and I must just alter it a little, and then it will go on smoothly. It is not intended for a galvanic battery (as used in this); but the idea has always existed in most people's minds that an electric light is a thing that is unmanageable. In this with the magneto-electric machine it is perfectly manageable: there is no difficulty whatever. All that the lightkeeper has to do is to mind this one regulator; if it hisses like that, all he does is to slacken this a little. If the light be too close, it hisses; if too far off, it jumps. In that way he knows by the sound whether this is over-wound or under-wound. An ordinary lightkeeper, with no more capacity than a bricklayer's labourer, can manage this.

The CHAIRMAN: Is this the lamp which has been in continual use for two years?

Professor HOLMES: Not all, but some of the time. At first my difficulty was the obtaining a lamp. I had Duboseq's, and then I tried Serin's. I tried different electric lamps, but they had always this fault, that a man never could leave them for fear they should go out from the complicated clock-work so frequently stopping. I was, therefore, as it were, driven to invent a lamp, having had such constant opportunities of experiencing what was actually required. It is impossible for this lamp to go out. There is nothing to prevent its burning, the same as it is now, for the whole time that the carbons will last; and the lightkeepers report that it has never gone out, from the time it was started to the present time. It is true that a lightkeeper has, through his own fault, put it out two or three times, simply through mismanagement. I will show you how it was done. The carbon has to be fixed in a kind of vice. Instead of screwing it up tight, he has left it loose, and upon lighting it the carbon has dropped out. The carbon having dropped out, he has simply to ascend and draw these two stops of the other lamp; that one lights, and he can remove this out of the way, and pass another in its place, so that he can again light it up. As their instructions are never to let the carbon burn out within a quarter of an inch, in case of an accident of that sort, they have always got time to light that up again, while they regulate the action of the light below. Again, it

takes ten minutes to change the carbons; but although it takes that time, the light is not out ten minutes, because one lamp is lighted in the upper lens, two lenses being fixed. One lamp is fixed above the other. While the carbon is being consumed in the upper one, the lower one is in its place ready to be lighted. It is simply to lock this top one, then, on drawing the bolts of the lower lamp, the carbons touch, put the upper one out, and light themselves, therefore the light itself is never missed. No mariner can miss the light, because one lamp is never put out except by the lighting of the other one.

MR. FINDLAY: It is said that the electric light is intended to be put in eight lighthouses in France. Are you aware of this?

PROFESSOR HOLMES: It is in France that the magneto-electric light was first shown by me. Since I left France I have improved upon it, and the improved form is the one I use now. The imperfect machine is the one used by the French, and they have admitted to me that it is not fit for lighthouses. M. Reynaud, the director of lighthouses in France, told me himself that he believed he should have to come to me, although I consider myself that a Frenchman has a very great objection to come to an Englishman for anything. He said, "I believe I shall have to come to you at last, for at present I will not put the light up." This light is steady, and theirs is not. The fault found with the machine, as made by me at first, was, that it was not permanent. Where I first obtained permission to put it up in a lighthouse, I saw at once that it was not the machine I required. I discarded it, and I made another that was more durable and permanent in its construction. The machines made by me now, cannot get out of order; whereas the first were continually getting out of order, being constructed more as experimental machines than machines for permanent use. Again, the French leave out a part of the machine which I call the "commutator." This is an apparatus which directs the compound currents of the machine, so that all the currents pass from the machine in one direction; without this, the light is always surrounded by a purpleish flame, which, besides obstructing a considerable amount of the white light that you have observed, gives the rest of it a decided purple tint. I can give you some idea of the difference between my light and the French light by separating the points thus:— You now perceive that the light is no longer white, and if you look at the reflection on this card, you will see a purple shadow where the light ought to be brightest. Moreover, the framework of these first machines was of wood, and therefore totally unfit for lighthouse purposes, where the atmosphere is so subject to change of temperature and humidity; and where, in consequence, the expansion and contraction of the wood might be the cause of serious accidents by bringing the magnets in contact with the wheels, which, in the French machines, revolve at a very high velocity—300 or 400 revolutions per minute. In the machines I make now, every part is of metal, and the revolutions are reduced to 100 per minute. Though the French Company talk about eight lighthouses, they have not yet had them, nor, from what I have heard, do I think it likely they will have, with their present form of machine. An accident to my machine is totally out of the question, and should there be an accident to the lamp, it can only arise through the breaking of a catgut or cord, and as there is merely a pulley to pass it through, any lightkeeper can receive another line, and that may be done in a few minutes. I may say that during the time it has been at Dungeness, two catguts have been replaced by the lightkeepers, and each of them has been broken by accident. But this does not arise from the wear of the lamp; simply this, that in cleaning this tube, they have pressed upon it, forced it down and broken the catgut. It is a simple apparatus, as there is no complicated clockwork. It is easily managed by any man, after five minutes' instruction. One of the elder brethren of the Trinity House, now present, learned to use it in five minutes, and taught another of the elder brethren in the same time.

THE CHAIRMAN: May I ask how long the charge of carbon will last.

PROFESSOR HOLMES: In preparing it for use, the length of the lower carbon is six inches, and the upper one a foot. They last three hours in a lighthouse.

THE CHAIRMAN: Then they require replenishing every three hours.

PROFESSOR HOLMES: Yes. But to do this, as I before explained, the light is not extinguished. The lightkeeper simply locks the lamp that is placed in one lens, and

draws the two bolts, already pointed out, of the lamp in the other lens. This second lamp is now lit. The one just used, in which the carbons are consumed, is drawn back on a small rail, when it passes on to a traverse rail, moving at right angles to the other rail. On this traverse, stands another lamp, with the carbons ready fixed for use. Suppose this standing to the right. The traverse is then moved to the left, till it comes against a stop, when the lamp, with its carbons fixed ready for use, is pushed forward on the first-mentioned rail, and, on coming against its stop, is exactly in focus with its lens. The two lenses are over one another, and the two stages for the lamps are exactly alike, and two lamps are employed for each lens. The used lamp is allowed to stand until it is cool, when the lightkeeper fixes it, at his leisure, a fresh pair of carbons.

The CHAIRMAN: This last explanation of the electric light has taken us somewhat away from the subject of Mr. Findlay's paper; and though the matter requires a considerable knowledge of optics, it may be that some gentlemen may wish to ask some questions.

Lord LOVAT: I should like to ask Professor Holmes a question, whether there is any standard as to the power of penetration of the light.

Professor HOLMES: The best standard I can give would be one or two testimonials. One is from Captain Pittock, of the "Frederick William." He left Dover on one occasion in a mist. After he had got seven miles out, it was found that some part of the machinery was broken, a bolt or something of that kind in the engine. They put back into smooth water off Dover to repair this. That delayed them about an hour and a half. They arrived late at Calais with the mail. At Calais, expecting the boat to arrive as usual, they made signal with a coloured light that there was not sufficient water on the bar for them to pass. After this signal had been burning some time, there was sufficient water on the bar, and they altered the signal. They then saw the steamer as they supposed outside the bar, and after waiting some considerable time and finding it did not come in, they sent a boat out to inquire the reason. Just as the boat was going out the "Frederick William" arrived, and ran into Calais. The question immediately was, "Why didn't you come in before?" The answer was, "We have only just arrived." They rejoined, "We saw you outside two hours ago." "No." "What is that light out there, then?" It was the electric light on the South Foreland; yet, through that mist, it was visible in Calais harbour, a distance of at least twenty-two miles, and Captain Pittock made his passage by it all the way across. When the steamer put back to repair, its lights were not visible from Dover through the mist, though the distance was only a mile and a-half. And the captain of the "John Penn" told me that in coming over in a very foggy night they tried to look out for any light they could see, but it was so foggy they could see none. At last he said, "We must take some soundings." On slackening the speed of the vessel, he observed a light which gave a little glimmer through the fog, and he at once saw that it was the electric light. He then took bearings from that, and made his way to Dover without any soundings. This was when the light was at the South Foreland. It is now at Dungeness, and from the alteration I made in the machine, it is more powerful. Again, a pilot named Goldsack, told Admiral Hamilton in the *Lantern* at the South Foreland, that he had brought a vessel from Beachy Head all the way up Channel without seeing any light but the electric light. He passed Beachy Head without seeing the light there, and he was then twenty miles from the South Foreland light, and he could see that, while he could not see the Beachy Head light which is a very powerful one. He passed Dungeness within a mile or two, and did not see that light, and he passed near enough to see the light at Cape Grisnez in ordinary weather, but could see nothing of it. He saw the electric light all the time, and anchored in the Downs at nine miles distance. Nothing could show more clearly the penetrating power of that light through mists. I may mention that at the illumination last Tuesday, at the Prince of Wales's marriage, it was the only light visible from Primrose-hill. Dr. Frankland went to Primrose-hill to observe the effect of the enormous amount of flame all over London. The whole of London appeared perfectly dark owing to the fog; not one ray reached Primrose-hill. But there was one little red light which he could see; and as the fog cleared off a little, he could perceive quite clearly that it was the electric light on the top of the

Monument, the only light that penetrated the fog on that occasion. On the same occasion, owing to there being less fog in the opposite direction, the light on the Monument was seen near Bromley, in Kent, a distance of about twelve miles, and there it appeared as a brilliant ball of light.

Captain HEATH, R.N.: I observed, when you showed the electric light just now in the central lens, a large number of coloured rays on the surfaces that reflected them. Is the same effect produced with your apparatus?

Professor HOLMES: Your question is a very pertinent one. It is quite true that this lens, which I am just now using, gives off a large amount of coloured rays; this is owing to the lens not being constructed expressly for so small a light. The focus of a perfect apparatus would be a mathematical point. Now, my light, compared with the large lamp previously exhibited in that lens, may be said to be a mathematical point,—not strictly so, but by comparison. Any point of light placed out of focus of a lens will give coloured rays, as the white light, in passing through the prisms or zones constituting the lens, in such a case will be decomposed. In the large oil-lamp all the points of that light are out of focus, and, therefore, all of them give coloured rays; but, as these coloured rays are passing in different directions, with different amounts of divergence, after leaving the lens, they mix again, and recombine white light, or nearly so. At Dungeness I have two lenses, one much better made than the other. In the one worst constructed, there are a large amount of coloured rays, because the light cannot be so placed as to be in focus with all parts of it; hence all those parts to which the light is out of focus give coloured rays; yet, strange as it may seem, at a distance the whole light appears white, and the reason of this may be thus explained: If the light, in this badly constructed lens, be observed at a distance of three or four miles through a tele-scope, it will be perceived that some of the zones give, say, red rays, and some green: on approaching or receding the colours reverse, but still the amount of green or red entering the eye at any time is about the same in quantity. I take these two colours as convenient for my illustration; but I might say the same of any pair of complementary colours. It is, however, well known that when two complementary colours enter the eye at the same time from what appears to be a point—and such the light may be conceived to be at a distance—the effect on the retina is the same as if the ray were perfectly white. One of these lenses at Dungeness I condemned, and have had a better one made and put in its place, in which these defects do not exist. It was not however condemned on account of the coloured rays, for they would blend as I have explained, but on account of loss of light from divergence, consequent upon its want of proper focus. You will perceive that the coloured rays only emanate from the zones around the centre lens, while the rays from the outer zones or prisms are perfectly white. The reason is, that these outer zones are what are termed prisms of total reflection, while the zones immediately around the centre lens are refractors.

Mr. FINDLAY: There is only one coloured light used in lighthouses, that is the red; all others are totally inapplicable. They are only seen for a mile; what would be the case with your light?

Professor HOLMES: This light being perfectly white shows every colour perfectly. A little while ago the oil-lamp, as you may have perceived, showed the red colour on this map very well, but not the green or blue, so as to distinguish one from the other; for there are not in fact sufficient blue rays or green rays in the oil-lamp to give enough light in these colours; but in this light, as there are all the colours, consequently it may be used for any colour in a lighthouse. I do not suppose there will be the shadow of a difference between the green and the red light in their penetrating power—that is in their brightness. Nor would there be the least difficulty in distinguishing the colour of the light at sea. Every one knows that a green light shown by an oil-lamp at sea is so imperfect, that it is frequently taken for a white one. In this case it is not only not so, but it is so perfectly perceptible that I believe it to be more effective than a red light. The red light here is magnificent, so is the green one; the red light from the oil-lamp is good, the green is bad, because in a lamp of that kind there are so many red rays and so few green. This light, on the contrary, enables you to give all the colours.

The CHAIRMAN: If no gentleman has any further questions to ask, I shall anti-

pate your intentions by expressing our thanks to Mr. Holmes for the way in which he has explained the penetrating power of this beautiful instrument of his. To be able to penetrate that dense fog last Tuesday is enough for every purpose. Nor should we forget Mr. Findlay who is the author of this very clever paper on light-houses. I may add that he is the author of one of the best books extant on the currents of the ocean, and that he is one of our very best geographers. We return our thanks to him for his excellent paper, and also to Admiral Collinson for his great kindness in reading it.
