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CHANCE

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LIGHTHOUSES.

By JAMES T. CHANCE, M.A., Assoc. Inst. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

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May 7, 1867.

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No. 1,180.—"On Optical Apparatus used in Lighthouses."[1] By James T. Chance, M.A., Assoc. Inst. C.E.[2]

The following notes are designed to convey a general idea of the chief contrivances which constitute the existing system of Lighthouse Illumination, and to trace the steps of their development.

The subject is of great practical importance, and furnishes an interesting application of optical science.

A complete sketch of Lighthouse Apparatus would far exceed the due limits of this Paper; and, moreover, the various questions connected with it have been systematically treated by the late Mr. Alan Stevenson and by Mr. Thomas Stevenson, M. Inst. C.E., to whose works the Author is indebted, as likewise to the following French sources, namely: 'The Mémoire of Augustin Fresnel,' which was read at the Academy of Sciences in July, 1822; 'The Report of the French Lighthouse Commission,' dated September, 1825; and the recent 'Mémoire of M. Léonce Reynaud,' Director of the French Lighthouse Service.

The object of Lighthouse Optical Apparatus is to condense, within a small equatorial zone, the available part of the rays which diverge in all directions from a given source of light; so that as much of it as possible shall be rendered serviceable to the mariner, in the most effective manner, compatible with the special conditions of each locality.

The ordinary source of illumination is the flame of an oil lamp on the Argand principle. A single cylindrical wick is employed in the small harbour lights of the dioptric construction, and also in nearly all kinds of apparatus which consists of metallic parabolic reflectors. But in dioptric sea lights the burner comprises two or more concentric wicks, four being used in the lamp which belongs to an apparatus of the first order; and as this arrangement necessitates a considerable superabundance of oil beyond what is wanted to

[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

[2] The Author was elected Assoc. Inst. C.E., May 21, 1867.

feed the flame, various methods have been adopted for producing the requisite uniform supply. The oil generally employed is the colza; in the lamp, however, with a single wick, it is being superseded by petroleum, which is cheaper and gives a more intense light than colza.

The magneto-electric spark has been successfully applied to lighthouse purposes, and it bids fair to be ultimately adopted at most of the important lighthouse stations which are ready of access and otherwise suitable. This brilliant source of light has been continuously used at Dungeness by the Trinity Board since the autumn of 1862, the magneto-electric machine being that of Mr. Holmes. The following remarks, however, upon lighthouse apparatus will refer mainly to the oil lamp as the source of light.

The Dioptric System.

The Optical Apparatus which is now being universally adopted for sea lights is of the dioptric kind, first successfully introduced by the eminent Augustin Fresnel.

It consists of a structure of glass zones, or segments, which in a complete apparatus envelopes the sphere of light radiating from the central flame, except that portion which is intercepted by the burner or is occupied by its chimney. Fig. 1,[1] Plate 15, which is in a plane of the vertical axis of the system, represents the sections which generate the successive zones, and which are such that all rays diverging from the principal focus are made to emerge in a horizontal direction. The vertical axis of the burner coincides, of course, with that of the apparatus. In reality the upper, middle, and lower portions of the system have generally different foci. An angle of about 57°, which the focal horizontal plane bisects, is acted upon by refraction alone; but the rays which pass above and below this angle are deflected by internal total reflection.

The generating sections may evidently describe zones, either round the vertical axis, or round a horizontal one through the focus.

If the vertical axis be that of generation, then all rays from the focus will be parallelized only in meridian planes, and the natural divergence in azimuth will remain, so that an uniform light will be distributed to every point of the compass. This constitutes what is termed a Fixed Light.

If, however, the axis of revolution be a horizontal one, the action of the apparatus becomes lenticular, so that all focal rays will emerge parallel to the axis of generation, which will also be that of the compound lens. All the sections may describe complete rings round the horizontal axis, and this is done occasionally in small apparatus; but the usual method is to divide the sphere into segments, by meri-

[1] The instrument represented in this figure is of the largest kind, and has a diameter of about 6 feet, and a height of about 9 feet.—J. T. C.

dian planes at equal angular intervals, the number of these divisions depending on the particular conditions to be satisfied, as to the recurrence and duration of the flashes. The interval adopted for most lights is that of 45°, as shown in Fig. 2. But whatever may be this angular division, each segment will send forth its own beam, in which all the focal rays will be parallel to the horizontal axis of revolution; and in order to render the series of separate beams serviceable to the mariner, the whole apparatus is made to revolve, so as to exhibit the appearance of an alternating succession of brightness and darkness, and hence is derived the designation, Revolving Light.

The flame has magnitude; and it is evident that on every point of the apparatus there is incident a conical beam of light, whose apex is that point, and whose directrix is the corresponding contour of the flame: and, if the ray passing through the focus be termed the axis of each individual cone, the axes of all the emerging beams will be parallelized, but the conical divergence will remain, though slightly modified, after transmission. This divergence can be diminished either by increasing the diameter of the apparatus, or by diminishing the size, and therefore the power, of the flame; but some divergence always remains, and is indeed indispensable both in azimuth and altitude for revolving lights, and in altitude for fixed ones. The difficulty in the former case consists in obtaining an adequate horizontal divergence without wasting light by useless vertical dispersion.

As the emerging light is always divergent, its intensity therefore, in any given direction, is subject to diminution in the ratio of the square of the distance.

The Revolving Light is evidently susceptible of much greater intensity than the fixed one, inasmuch as all the light abstracted in the revolving apparatus from the dark intervals contributes a proportionate increase of brilliancy. Thus in a first-order revolving dioptric light of eight sides, as the whole 360° are compressed into eight beams whose divergence is about $5\frac{3}{4}°$, the mean intensity of the flash will be about eight times that of the fixed first-order light. The intensity, indeed, of the brightest part of the flash in a horizontal plane, as measured by observation, is at least twelve times[1] that of the fixed light. In consequence, however, of the necessity of distinguishing lights, the fixed one, although so inferior in power, cannot be dispensed with. The diameter of the largest, or first-order apparatus, is rather more than 6 feet, and that of its quadruple flame is about $3\frac{1}{2}$ inches; the height of the flame above its blue portion being about equal to its diameter. As the flame is diminished in power and size, according to the requirements of the locality to be lighted, so does it subtend a less angle, and

[1] It is assumed that the axes of generation of the upper, middle, and lower divisions of the apparatus coincide, or are in the same vertical plane.—J. T. C.

therefore the optical apparatus can be proportionately reduced. There are, accordingly, a second-order light, which has a flame with three wicks, and a third-order one, having a flame with two wicks. Then follows the gradation of harbour lights of different sizes, according to the power required.

Now although the flame of a sea light is large, the most effective part of it is comprised within a small compass, and subtends only a small angle at the centre of the lens. Again, the angle subtended in a meridian plane by the greater portion of the sea between the visible horizon and the lighthouse is also extremely small, so that practically whatever part of the flame sends light to the sea horizon is at the same time illuminating the chief range of the sea landwards. Thus, suppose the flame to be placed 300 feet above the sea, the distance of the horizon is twenty nautical miles; and yet fifteen miles from the horizon towards the lighthouse subtend only seventeen minutes, which angle corresponds to about $\frac{1}{7}$th of an inch at the axis of the flame in a first-order light. Hence the brightest sections of the flame, which correspond to the different parts of the apparatus, ought to send their rays to the horizon; that is, each successive zone ought to be both shaped and adjusted with such accuracy that the sea horizon focus shall be situated in the corresponding brightest section of the flame. This adjustment is now generally attended to, and for this improvement the mariner is indebted in a great measure to the late Royal Commission; but in consequence of the prevailing misconception, that the size of the flame renders accuracy of shape comparatively unimportant, this latter desideratum is often neglected; and yet it is evident that if the middle of any particular zone be made to do its due work by means of adjustment, the whole of that zone ought to co-operate with its middle portion; and this can be effected only by the accuracy of its generating section.

This will be somewhat clearer when the subject is considered more in detail; but it must be manifest even from a general description, how immense must be the difference in power between one apparatus of which the parts are ground in conformity with theoretical accuracy of form, and which sends upon the sea only the brightest part of the flame, and another whose zones are so shaped that although the small middle portion may by adjustment be made to produce this effect, the remainder of it, perhaps, is sending the weak portion of the flame on the sea and the brightest part towards the sky, or else near the foot of the lighthouse itself. But this is not all; for as the axes of the emerging conical beams diverge instead of being parallel to each other, the light is diluted in every plane of the generating sections in proportion to this divergence.

The portion of the whole sphere which is embraced by the entire glass structure, after deducting the metallic framing, is about

81 per cent., which is distributed among the three divisions of the apparatus in the following proportions: the upper reflectors $22\frac{1}{2}$, the refracting belt 45, and the lower reflectors $13\frac{1}{2}$; but these ratios do not represent the actual relative illuminating values of the three portions. For several disadvantages appertain to the reflectors in comparison with the refracting division: first, the respective focal sections of the flame corresponding to them are weaker, and in the lower reflectors a degree of accuracy, scarcely ever yet obtained, is necessary to render effective the limited flame-section which sends its light to them; secondly, the longer paths described in the prisms involve greater loss by absorption; thirdly, the light which is transmitted by the reflectors has suffered more diminution by the greater obliquity of incidence, both at the two surfaces of the glass chimney and also at those of the prisms themselves. It is true that the longer focal distances of the reflectors, as compared with the refractor, are attended with a greater condensation of the emerging light; but the balance of these optical considerations is much in favour of the refracting portion, so that, as actual experiments seem to indicate, the relative illuminating values in the horizontal plane are approximately thus: for the refracting belt, 70, the upper reflectors, 20, the lower reflectors, 10.

Each zone, or ring, of the apparatus may have its own separate focus in the flame; but the general practice is to assign a common focal point to each of the three main divisions of the general vertical section, as shown in Fig. 2. Thus, while the focus of the refracting section is in the vertical axis, the upper reflectors have theirs at a short distance behind it, so as to combine with one of the most intense focal sections, corresponding to each prism, an adequate vertical angular range of light on the sea; and the focus of the lower reflectors is in the front of the flame, at the brightest section compatible with some amount of vertical divergence below the horizon-direction.

According to the usual plan now adopted, the lowest film of the brightest part of the flame is made to contain the sea horizon focus of the refracting panel; and then the reflecting zones or segments are so adjusted that their respective sea horizon foci shall be situated in the flame in positions which are in accordance with the principles just explained.

Too much stress cannot be laid upon the importance of selecting for the horizon, and sending towards it, through the various parts of the dioptric instrument, the corresponding brightest sections of the flame. The light ought to be visible to the approaching mariner as soon as the farthest horizon, which he can command, touches the horizon of the centre of the lantern; so that, in estimating the full optical range, the distances of these two horizons, from the lighthouse and the mariner respectively, must be added together. Now the emerging light, as has been already stated, is divergent, so that its intensity is subject to diminution in the ratio of the square of the distance; and there is a further loss of light, arising from the imperfect transparency of the atmosphere, which increases as the distance is augmented, though not in a direct ratio. Thus, in a clear state of the sky, each nautical mile abstracts from ordinary light five per cent. of the intensity with which it began to traverse that distance.

Let the intensity *in vacuo* at the end of the first nautical mile from the lighthouse be unity, then the respective intensities at successive miles in a clear atmosphere will form the series

$$\cdot 95 \quad . \frac{(\cdot 95)^2}{2^2} \quad . \quad \frac{(\cdot 95)^3}{3^2} \quad . \ . \ . \ . \ . \ . \ . \frac{(\cdot 95)^n}{n^2}$$

where n is the number of miles; and generally, if I be the intensity *in vacuo* at the distance of the first nautical mile, and p the proportion of the quantity of light absorbed by each mile, the intensity at the distance of n miles will be

$$\frac{I\,(1-p)^n}{n^2}$$

When the atmosphere is hazy, the luminous range even of the brightest part of the rays is so limited, that a doubt may occur to some as to the expediency of directing the most intense light tangentially to the sea surface. But to rob the horizon of any light is to subject to the same decrease of illumination the chief sea range landwards, as has been before explained; and moreover, any increment of intensity thus obtained, even at a short distance from the lighthouse, will be scarcely appreciable in misty weather. If, however, it be desired to have a powerful dipping light, this should be provided by some accessory contrivance which will not interfere with the normal state of the main apparatus.

It is not intended to enter upon the various questions which concern the distribution of sea lights on a coast, and their adaptation to special localities. The solution of most problems of this kind requires not only a familiarity with the optical facilities which the dioptric system affords, but also a knowledge of the conditions which nautical experience supplies.

It suffices to remark that one chief difficulty which is encountered by lighthouse Engineers consists in devising admissible characteristic distinctions among sea lights, subsidiary to the two grand divisions, fixed and revolving. He is occasionally forced to resort to colour; but the want of power in penetrating the atmosphere excludes generally all colours except red; and even in red colour the initial intensity is so reduced by passing through the colouring medium, that whenever it is employed in company with white light, special contrivances should be introduced into the apparatus in order to equalize nearly[1] the luminous intensities of the two kinds of light. This can be for the most part accomplished in the first instance in designing any particular instrument; therefore it is very important that any question of introducing coloured beams of light should be settled before the construction of the apparatus has been commenced.

A full account of the various modes of distinguishing lights will be found in the treatise of Mr. Alan Stevenson.

The Annular Lens of Augustin Fresnel, and the Cylindrical Refractor.

The Dioptric system will now be described in detail; and first, the annular lens of Augustin Fresnel.

No one can adequately appreciate the admirable combination of exact science with practical ingenuity which Fresnel displayed, in devising and carrying out in detail his annular lens and its accessories, without having perused his celebrated Mémoire which was read before the Academy of Sciences in July, 1822.

A Commission on Lighthouses had been appointed in France as early as 1811; and at the request of Arago, who had in 1813 joined the Board, Fresnel and Mathieu, a Member of the Institute, were in 1819 associated with him in conducting the necessary experiments and researches.

It is, indeed, creditable to the Administration in France that her highest men of science should be thus enlisted in the investigation of a national question requiring scientific treatment; and the result in this instance proved the wisdom of the selection. In September, 1822, the Commission confirmed an elaborate report, drawn up by Admiral de Rossel, in which Fresnel's system was adopted, and a programme was presented for the systematic lighting of the sea-coasts and harbours of France. This scheme was gradually carried into effect, and so strictly has it been adhered to, that out of forty-nine sea-lights which were proposed, only ten have been modified in their character, and the employment of metallic reflectors in sea-lights has been reduced to the single instance of a secondary lighthouse at Pontaillac, at the mouth of the Gironde.

Fresnel selected the annular form of lens, because, while it afforded the means of reducing considerably the substance of the glass, it also enabled him to give to each ring its own individual shape, so as to correct spherical aberration.

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[1] The word *nearly* is used, because red light, as might be anticipated *à priori*, loses a less proportion of its intensity than white light in passing through the atmosphere, especially in hazy weather; so that, with *equal* initial intensities, a red beam will have a longer luminous range than a white one.—J. T. C.

He seems to have been quite unaware both of Buffon's proposal, in 1748, to form a lens *à échelons* out of a solid piece of glass for the purpose of a burning instrument, and of Condorcet's valuable improvement, in 1788, of Buffon's idea, by suggesting that the burning lens should be constructed of separate rings. But, however this may be, Fresnel was the first to apply the lens effectively as a lighthouse instrument. His lens is plano-convex: he seems to have chosen this form chiefly for the sake of facility of execution; but it is also the best shape optically, for unless the angle subtended at the focus by the lenticular section be much diminished, concavity of the inner surface would render the external surfaces too oblique; and if the inner surface be convex, the angles of incidence in receding from the axis would be very disadvantageously increased; so that the total loss by reflection in each case would be greater than in Fresnel's arrangement, which assigns fairly to each surface its proper share in the total deflection required at each point.[1]

The only spherical surface in the lens is that of the central disc; the convex surfaces of all the encircling rings being annular ones, generated round the lenticular axis by circular arcs in the plane of that axis, but having their centres beyond it in a series of points which retreat further from the axis as each corresponding ring is increased in diameter.

The true generating arc for accurately parallelizing the rays from the focus is, of course, not a circular one, as its execution would be impossible; Fresnel, however, so calculated the co-ordinates of the respective centres of the actual arcs that the two extreme rays are made to emerge parallel to the axis. Now this approximation so nearly corrects aberration, that the greatest deviation, from the direction of the axis, of focal rays emerging from each of the successive rings varies in a diminishing progression from 2 min. 32 sec. for the ring next to the disc to 52 seconds at the eighth one.[2]

Fresnel at first encountered an obstacle in the optician's workshop, where none but the spherical form could be produced; rather, therefore, than lose time in his preliminary experiments, he composed each ring of small pieces having spherical surfaces indeed, but so calculated, in regard to curvature and obliquity, as to give the minimum mean aberration in all directions; and he also made it polygonal, in order still further to facilitate the execution.

His versatile genius, however, was not baffled by this temporary

[1] These considerations are not intended to apply beyond the actual ordinary limits within which refraction alone is employed in Lighthouse Apparatus.—J. T. C.

[2] This gradual diminution of the maximum deviation arises from a corresponding decrease of the angle subtended at the focus by the breadth of each successive ring as it is further from the axis; without which latter decrease the angles would project inconveniently, and the thickness of glass would become too great.—J. T. C.

impediment; and he contrived expressly a system of grinding the glass rings by combining a cross stroke with rotation; thus translating, indeed, his geometrical conceptions into corresponding mechanism: and in realizing this design he found a zealous coadjutor in M. Soleil, by whom, with the encouragement of the French Government, the annular lens was successfully constructed. Fresnel's first lens was 30 inches square, and subtended at the focus 45°, vertically and horizontally; the focal distance being 36·22 inches (920 mm.). The lens now used in a first-order light, as shown in Fig. 2, has the same horizontal extent, but subtends 57° vertically, so that eight of them form a regular vertical prism, with a common focus, and enclose an equatorial belt of 57°, or about 47·7 per cent. of the whole luminous sphere, but in fact 55·75 per cent. of that portion of the sphere which the entire apparatus of glass embraces. The diagonal of the octagonal horizontal section is about two metres; which perhaps, therefore, was the origin of the present focal distance.

There was still wanting a powerful flame; and for this purpose MM. Arago and Fresnel availed themselves of Count Rumford's idea of a multiple burner, and succeeded in constructing a lamp with four concentric cylindrical wicks. Carcel's contrivance for supplying and regulating an overflow of oil was essential to the due performance of the multiple burner; for unless it is cooled by a superabundance of oil, its accumulating heat not only volatilizes the oil, but also causes the deposit of carbon upon the wick. An adequate draught-pipe, with a contrivance for regulating its power, supplied a constant renewal of air for perfect ignition; and the proportionate quantities of air required for each individual flame, were secured by a corresponding ratio between the outer aperture and each of the inner ones by which air was admitted. This was determined by a series of experiments.

The intense heat of the four flames, which is rendered harmless by the overflow of oil, and by the rapid ingress of cool air, promotes such a thorough decomposition of the gaseous products of the oil, that a given quantity of it produces, in the four-wicked lamp, a greater illuminating effect than if burned in separate Argand, or Carcel lamps. Thus, if the French unit of light be adopted, which is that of a Carcel lamp 20 mm. in diameter, and burning 40 grammes of colza oil per hour, it is shown that a lamp with four wicks can be made to give the light of twenty-three such lamps, and yet will burn only 760 grammes of oil per hour, or what nineteen of the single lamps would consume.

It is remarkable how many inventors have contributed their respective parts to the multiple burner:—Argand, the double current; Lange, the indispensable contraction of the glass chimney; Carcel, the mechanism for an abundant supply of oil; and Count

Rumford, an idea, made feasible by these contrivances, and finally realized by Arago and Augustin Fresnel.

While the angle subtended by the flame at any point of the generating section of the annular lens decreases as the point recedes from the axis, the corresponding angle of divergence in the emerging beam does not decrease, but, on the contrary, it increases. Take into consideration, for example, the horizontal focal section in a first-order light. The angle subtended by the diameter of the flame at the lens varies from 5° 36′ at its centre, to 5° 12′ at its extremity; while between the same limits the corresponding angles of divergence, after transmission, vary from 5° 30′ to 5° 45′, in a converse progression.

The collective effect of the lens will be understood by what has been premised; it sends forward an infinite number of conical beams, which radiate from within its substance, and whose axes, as already defined, are all parallel to that of the lens; so that, at a moderate distance, the aggregate effect is one conical beam, whose axis is the lenticular one. The intensity of this collective conical beam varies in different directions, according to the corresponding parts of the flame from which the rays proceed; the maximum intensity is, of course, in the direction of the axis, from which the brilliancy gradually diminishes, until it becomes a minimum at the boundary of the beam. It has been found by observation that, in the horizontal plane, this gradation of intensity varies in a first-order lens from about 5,000 burners to 1,000 burners, of the French unit.

The refracting belt of the fixed light is cylindrical, and is formed by the revolution of the vertical central section of the annular lens round the vertical axis of the system, so that this belt is lenticular in every meridian plane, but not so in any horizontal one; and hence the central light retains its natural divergence in azimuth, and thus distributes, in every direction of the horizon, a uniform illumination.

The difficulty here, as with the annular lens, was the execution; and for years the refracting portion of the fixed light was a polygonal regular prism, the normal vertical section of each of its sides being the same as the meridian section of the cylindrical belt: but, of course, the illuminating effect in azimuth varied in each side, from its maximum at the middle vertical section, to its minimum at the angles. In the first-order light there were thirty-two sides.

The late Mr. Alan Stevenson, who had charge of the introduction into Scotland of the Fresnel system, was the first to carry out the cylindrical shape of the refractor: this he did at the Isle of May, where the first British dioptric fixed light was erected in 1836; the work having been executed at the manufactory of Messrs. Cookson and Co., of Newcastle, who subsequently constructed several lenses and cylindrical refractors for the Lighthouse Boards of this kingdom.

Mr. Alan Stevenson soon afterwards applied oblique joints to the cylindrical refractor, in order to avoid the intercepting of light caused by vertical ones.

The Commissioners of the Northern Lighthouses were the first to carry into effect, in this kingdom, the adoption of Fresnel's invention. It was proposed to them by their Engineer, the late Mr. Robert Stevenson, in consequence of a communication which he had received from General, then Major, Colby, R.E., at that time engaged in the Ordnance Survey of the British Channel.

And here it may be remarked, that the introduction of the dioptric system into this country had a zealous advocate in Sir David Brewster, who at once recognized its unquestionable superiority over the method of metallic parabolic reflectors.

The Catadioptric, or Totally-reflecting, Zones.

There is a limit[1] beyond which prismatic deflection becomes wasteful, partly by chromatic dispersion, and partly from the increasing loss by reflection at the surfaces of incidence and emergence. It occurred to Fresnel to employ totally-reflecting zones; and he actually introduced them above and below the refracting belt of his fixed Harbour Light, which was 30 centimetres in diameter; and it is asserted that reflecting segments, generated round a horizontal axis, were applied by him to a small apparatus at Paris, upon the Quay of the Canal St. Martin.

The late Mr. Alan Stevenson, however, the Engineer of the celebrated Skerryvore Lighthouse, was the first to extend the application of horizontal reflecting zones to dioptric apparatus of large dimensions. He introduced them in the lower portion of the revolving light which was placed at Skerryvore, and exhibited for the first time in February, 1843. They were executed by M. François Soleil, of Paris.

Mr. Thomas Stevenson, quite unaware of everything relating to the small instrument on the Canal St. Martin, proposed, on the 30th of March, 1849, in a Paper read before the Royal Scottish Society of Arts,[2] that reflecting prisms should be generated round a horizontal axis, so as to have a lenticular action, like that of the refracting lens. These prisms were first introduced by Messrs. Stevenson on the small scale at Horsburgh Lighthouse, near Singapore, which was shown to the mariner in October, 1851; and

[1] It is not assumed here that prismatic deflection is, at present, actually extended as far as it can be advantageously employed.—J. T. C.

[2] There seems to be no evidence that any account of the lenticular reflecting prisms of the Canal St. Martin Light was ever published, or that any proposal was made to employ such prisms for lighthouse purposes, previously to that of Mr. Thomas Stevenson on the 30th March, 1849.—J. T. C.

in January, 1851, the Commissioners of the Northern Lighthouses ordered vertical reflecting zones to be adopted in the first-order revolving apparatus intended for North Ronaldshay.

Hitherto, silvered mirrors—sometimes plane, sometimes concave,[1] —had been used to show a fixed light beneath the great lenses of a revolving apparatus; and the rays above these lenses had been gathered into separate beams by small lenses, forming together a truncated pyramid above the flame, and then directed upon the horizon by a corresponding number of plane silvered mirrors. This arrangement was introduced at the first revolving light which was constructed under Fresnel's guidance, and which was exhibited at Cordouan in 1823: it is exactly the same in principle as that which Sir David Brewster devised for burning instruments, and which he described in 1812 in the Edinburgh Encyclopædia.

This invention of Sir D. Brewster is admirable for a burning instrument, because it intercepts a calorific beam of large diameter, and yet brings it to a minute focus; a result which a large lens cannot produce. But this very feature of the shortened focal distance unfits the plan generally for the purpose of condensing flame-light; and accordingly, in Fresnel's revolving apparatus, as the focal distance of the accessory lenses is less than one half of the shortest focal distance in the system of reflecting zones, the intensity of the light issuing from the former would be scarcely more[2] than one fourth of that transmitted by the latter; and, in addition to this cause of inferiority, is the loss arising at the mirrors; so that, on the whole, the modern plan must give light five or six times more intense than that of the former arrangement.

Of course Fresnel was well aware of these disadvantages; but he was limited to the contrivances which could in his time be executed. To compensate, however, in some measure for the reduction of intensity which arose from the short focal distance of the small accessory lenses, Fresnel obtained from them a flash of double horizontal divergence, and this he turned to good account, by causing it to precede that of the lenses, so as to increase threefold the duration of the total flash; the diminution of the length of eclipse being a point on which he laid great stress in his Mémoire, and on which the Engineers of the French Lighthouse Board still insist, as of more importance than the increase of the intensity of the flash.

The principle upon which Fresnel calculated the generating section of the reflecting zone, was that of dispensing with all superfluous glass.

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[1] These mirrors were also employed in fixed lights above and below the refracting portion of the apparatus.—J. T. C.

[2] The words, *scarcely more*, are used in order to allow for the greater loss of light caused by the prisms than by the lenses in consequence of the longer paths of the rays in glass.—J. T. C.

Let B F C, in Fig. 3, Plate 15, be an angle of light from the radiant point F; and B C A, the generating triangle, in the plane of B F C.

In order to avoid all redundant glass, the side C A must be the path of the ray F C, after its refraction at C, and the side B C must be the path of the ray F B, after its refraction and reflection at B. Hence, if C R be the direction of the ray B C, after emerging at C, the angles B C F and A C R are equal to each other; and the angle D C R, which the emerging ray makes with the incident one, being of course given, the angle B C F is determinable,[1] and therefore B C A.

The distance F C, and the angle B F C, are also given; so that the side B C of the section is known.

The reflecting side, B A, is curved; but instead of the true curve, a circular arc is necessarily adopted. The respective inclinations of this arc at B, and at its intersection with C A, are so determined that the refracted ray at B shall be reflected along B C, and that the ray C A shall be reflected in a path which, after refraction at the side C A, shall take the given direction at A.

The problem then is solved generally. In the particular case under consideration, the ray at A is made to emerge parallel to that at C; and in regard to the rest of the beam, so slight is the deviation that, for the ray which is incident at the middle point of B C, it is quite inappreciable: thus, in the first prism next to the refractor in Fig. 1, the deviation of this middle ray from a horizontal direction is only 3 minutes.

The slightest inaccuracy in the shape of the section will cause the emerging beam to be either diverging or converging, and, therefore, weakened in intensity in proportion to its increased dispersion in the plane of the section.

It will be evident that in all generating sections, for the same angle of light B F C, and the same condition of emergence, the angular elements will be constant; and that, if the length of F C is altered, the linear dimensions only will be changed.

The angles of incidence on entering the upper prisms decrease from 44° at the first of the prisms to $11\frac{1}{2}°$ at the furthest; and there is a similar diminishing progression from 27° to $7\frac{1}{2}°$ in the angles of incidence on emergence: but this may be considered to be compensated by the contrary order of progression in the angles

[1] $BCA = \frac{\pi}{2} + \sin^{-1}\left(\frac{\cos. BCF}{\mu}\right)$, where μ = the refractive index: and $ACR = BCF$. Therefore $2BCF + \frac{\pi}{2} + \sin^{-1}\left(\frac{\cos. BCF}{\mu}\right) - DCR = \pi$.

$$\therefore \cos BCF = \mu \cos. (2\,BCF - DCR);$$

or, if ξ = angle of incidence at C, and $\theta = \frac{\pi}{2} - DCR$, $\sin \xi = \mu \sin (2\xi - \theta)$, as given by Mr. Alan Stevenson in his treatise.—J. T. C.

at which the light is incident, both on entering and on emerging from the glass chimney of the lamp.

It is suggested in the Appendix to the Report of the late Royal Commission, that the incidence on the prisms should be a normal one even at both the surfaces, external and internal. This can of course be done, it is merely to add superfluous glass, as shown in Fig. 4, and to calculate the reflecting side accordingly. But the consequent diminution of loss of light by reflection at the two surfaces would be far more than neutralized by the increased absorption resulting from the lengthened paths of the rays in glass, and also by the serious addition to the dimensions and weight of the apparatus, which latter effect even in a fixed light would be objectionable, and in a revolving one far more so.

It might be better in the reflecting section to cause the side B C to be the path of the ray which proceeds from the lowest part of the front of the corresponding section of the flame, because, in the present construction, a small portion of the prism at B is useless for all light below the focal direction. Also, strictly, each successive section ought to be so situated in the angle B F C, that the ray incident at B from the above-named lowest part of the flame should, on emerging at C, just graze the point A of the section next below it; at present the point C of the former and the point A of the latter are placed upon the same horizontal line.

In the smaller sizes of fixed lights no metallic rings are required between the refractor and each of the reflecting zones next above and below it; hence, in order to prevent the void spaces from subtending any angle at the focus, whereby light would be lost, the point C of the prism in each case must be outside the refractor, on the prolongation of the focal ray which touches its edge. In the employment of the electric spark in small apparatus this is absolutely necessary: and although it may be objected to this arrangement, that the extra size of each prism, unless an additional one be introduced, would cause increased loss by absorption, yet, when a flame is employed, this would be compensated for by the diminution in divergence corresponding to the lengthening of the focal distances.

The Method of Testing and Adjusting.

The paramount importance of extreme accuracy of shape and adjustment in every part of a dioptric apparatus has already been mentioned. It follows, therefore, that the essence of successful execution consists in the possession of a simple critical test of accuracy. Linear and angular measurements do not suffice. The most ready, and, at the same time, the most certain method of verification, is the optical one of internal observation; and the employment of this for the reflecting zones has produced a vast improvement in the efficiency of dioptric lights during late years. It is likewise applicable to the lens and the refracting belt; but as the method of conjugate foci, as explained by Mr. Alan Stevenson in his Treatise, could always be used in examining these portions, the plan of internal observation, although far more convenient and critical, was not so great a desideratum as in the case of the reflecting zones.

The system of internal observation during the process of manufacture is this: the ring or segment to be tested is fixed in a temporary frame in its due position relatively to the focus of the corresponding part of the apparatus, which point is indicated by a suitable instrument; a well-defined object is placed in front of the frame at a considerable distance, in the horizontal plane which bisects the part[1] of the glass piece under examination; the eye, placed at a convenient distance behind the focus, views the direction in which the image of the external object is seen through the middle of the section of the prism in the vertical plane passing through the focus and the object, and readily notices any deviation from the focus: also by moving the eye up and down in the vertical plane, it is easy to ascertain the position of the actual focus of the entire section for the pencil coming from the centre of the object, so as to determine whether the effect of the glass section is too converging, or the contrary.

The position of the due focus of the object will be very near to the focus of parallel rays, if the object is at a sufficient distance for that purpose. If the segment, or ring, be finally made to revolve round its axis of generation, every meridian section of it may be treated in like manner: but generally the simple motion of the eye, after a little practice, will, with proper allowance for the fixed position of the external object, suffice to extend the examination throughout the glass.[2]

The same process is adopted for the final adjustment and verification of the various parts of the apparatus in its permanent frame: the only difference being that the external object is placed in succession in the sea-horizon direction for each zone instead of in the horizontal line.

Similarly any dioptric apparatus may be adjusted and tested, however complicated the combination of its parts.

The method of adjusting by the image of the horizon began to be practised when the first Fresnel apparatus was erected at

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[1] In the case of a vertical ring or segment this part is, of course, a section made by the vertical plane through its axis of generation.—J. T. C.

[2] Strictly, the generating sections of the reflecting zones ought to agree with the due positions of their sea-horizon foci; and as an approximation, generally suitable, these sections might be made and tested in the first instance to correspond with a given depression of the horizon, such as an angle of ten minutes.—J. T. C.

Cordouan, but it seems to have been used only for the auxiliary mirrors. Its general application to lighthouse optical instruments is only of recent origin; and as the constructor and the inspector are thereby furnished with a test, which is perfectly accurate, and yet extremely simple, for examining both the shape and the adjustment of every part of an illuminating apparatus; and as the use of this system effected at once a thorough change in the practical part of lighthouse optics, it will not be a digression to allude briefly to the circumstances of its introduction.

The recent Royal Commission on Lighthouses deserves the merit[1] of first directing attention to the mode of examining sea-lights, by means of the sea-horizon image: and in doing so they availed themselves of the valuable scientific aid of the Astronomer-Royal.

In examining certain lights on the coasts of England and France, Professor Airy tested the adjustments and shapes of the various portions of each apparatus by observing with unaided vision in what directions the axes of pencils of light from the horizon, or from objects on the sea, crossed the burner of the lamp; and also where on their respective axes the foci of these pencils were situated.

He was much struck with the extreme importance, as well as with the simplicity, somewhat unexpected, of a test so searching and infallible. After his visit to the lights at Whitby he wrote to the Author in June, 1860, thus:—

"I very much wish that I could induce you to look at the Whitby lights. I think that it would lead to an extensive and beneficial revolution in lighthouses."

The Author soon afterwards, at the request of the Trinity Board, undertook the readjustment of the Whitby lights, and was at once satisfied, that the internal method of observation fully realized the value attached to it by the Royal Commission and by Professor Airy.

Fortunately the weather was hazy during several days, which rendered it necessary to resort to some substitute for the sea-horizon: a staff, Fig. 1, was fixed vertically upon an elevated position in the vicinity, and a middle belt of one of the refractors being used as a theodolite, the level was taken of its centre: the depression due to the dip of the visible horizon was then allowed for, and the staff was graduated so as to correspond with the successive zones above and below the refracting portion. The apparatus itself was made to revolve, in order to place every segmental division in its turn opposite the staff, without disturbing the level of the focal plane.

The adjustments were then effected; and when the atmosphere became clear, they were found to correspond exactly with those which the images of the sea-horizon itself would have indicated.

[1] The Commissioners in their Report attribute to their Secretary, Mr. J. F. Campbell, of Islay, the valuable plan of internal observation.—J .T. C.

It was, therefore, evident that, by pursuing a similar process at the manufactory, the most unerring certainty of final accuracy of adjustment might be insured. This the Author had an opportunity of at once putting into practice; inasmuch as the three dioptric lights that were destined for the iron towers, which Mr. W. Parkes, M. Inst. C.E., had designed for lighthouses in the Red Sea,[1] were waiting for their final adjustment. The result considerably exceeded that which was anticipated: not only was perfect accuracy attained, but the operation of adjustment was rendered far more rapid than what could previously be accomplished.

One rule, however, is imperative: it will be evident that not a segment of glass should be placed in an apparatus before the whole framework has been fitted together, just as it will be at its ultimate destination, and has been accurately levelled.

Nothing could be more unscientific than the system which was, until a recent date, frequently practised by the lighthouse authorities of this country: the manufacturer of lighthouse apparatus often supplied the separate panels only ,having the glass permanently fixed in them; and an intervening constructor was employed to frame them together.

There are many serious objections to such a course. First, it is almost impracticable to secure accuracy in the first instance, if in adjusting the glass the apparatus is treated in successive portions and not as a whole: Secondly, the primary adjustments, however carefully they may have been made, will invariably be altered in the hands of the second person; for an error of even the one hundredth of an inch in the level of any part will cause a serious deflection: Thirdly, the responsibility is divided.

Perhaps it is scarcely necessary to add, that during the adjustment of the glass zones the frame of the apparatus should not be disturbed. Thus if a workman supports himself on the frame, the level may be deranged during the process: and also in the case of a revolving light, any horizontal oscillation of the apparatus should be securely prevented.

The Parabolic Metallic Reflector.

This instrument is still employed in one half of the sea-lights of this kingdom. In January, 1867, there were the following lights on the coasts of the United Kingdom:—

	Dioptric.	Catoptric.	Total.
England and the Channel Islands . .	35	38	73
Scotland and the Isle of Man . . .	31	20	51
Ireland	25	30	55
	91	88	179

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 1, *et seq.*

The parabolic mirror must not, therefore, be passed by unnoticed. The idea of its application to sea-lights soon followed the invention, in 1784, of the cylindrical burner with its double current of air. The chimney, that was essential to perfect combustion, served likewise the indispensable purpose of carrying off the gaseous products, which in previous forms of lamp, by tarnishing the surface of a reflector, rendered its adoption quite futile.

Argand, who is generally recognized as the author of this valuable lamp, seems to have perceived at the same time the applicability of the parabolic reflector for sea-lights; and Teulère, who, as early as 1783, proposed the latter arrangement, has also some claim to have originated, independently of Argand, the idea of the double current burner.

Teulère's reflector was carried into effect by Borda at the Lighthouse of Cordouan, and it is remarkable that on this tower were exhibited the first sea-light consisting of parabolic mirrors, and, about thirty years later, the first Fresnel dioptric apparatus.

It should not be omitted that parabolic reflectors, composed of facets of silvered glass fixed in a plaster mould, were erected in 1787 at Kinnairdhead, in Aberdeenshire, under the direction of the Northern Lights' Board; being the contrivance of their Engineer, Mr. Thomas Smith, who seems to have been quite ignorant of what was being suggested in France with the same object.

Sir David Brewster,[1] and other eminent writers on light, have shown how much greater is the loss of power when rays are reflected from a metallic surface, especially if hammered into shape, as in the case of the ordinary parabolic reflectors, than when transmitted through glass lenses or prisms of moderate thickness. Experimental results to the same effect are given by Mr. Thomas Stevenson in his work on Lighthouse Illumination, published in 1859; and he also points out the great superiority of glass in comparison with the metal of lighthouse reflectors, in admitting and retaining a high polish and accuracy of shape.

But, apart from these considerations, the lighthouse reflector gives place to the dioptric instrument for two other reasons mainly. First, the parabolic mirror irremediably causes great waste of light, and therefore of oil, by useless divergence: Secondly, it is only by an enormous multiplication of reflectors, far beyond what, in the presence of a better system, engineering principles would justify, that the power of dioptric sea-lights can be rivalled. Theory and experiment concur in this result.

There are three principal sizes of parabolic reflectors which are adopted in this country. The English type of mirror has an aperture of 21 inches and a depth of 9 inches, which give a focal distance of 3 inches at the vertex. The ordinary Scotch reflector has the same

[1] *Vide* Transactions Royal Society of Edinburgh, vol. xi., 1831.

aperture, but the focal distance of its vertex is 4 inches, which give a depth of nearly 7 inches; but in Scotch revolving lights another size of reflector is also used, which has the same focal distance at the vertex, but an aperture of 25 inches, and therefore a depth of rather more than $9\frac{3}{4}$ inches.

Were it not for the shadow of the burner, and the small aperture occupied by the chimney, the following would be the portions of the luminous sphere included by the English, the Scotch Fixed, and the Scotch Revolving types respectively, namely,

English.	Scotch Fixed.	Scotch Revolving.
74·6	63·3	71 per cent.

The burner used in England has a diameter of $\frac{7}{8}$ths of an inch; that in Scotland has a diameter of one inch.

The theoretical angles of divergence at the vertex, at the extremity of the parameter, and at the terminating point of the horizontal generating parabola, are:—

	Vertex.			Extremity of Parameter.			Edge.		
	°	′	″	°	′	″	°	′	″
In the English Reflector	16	25	36	8	11	32	4	9	26
In the Scotch Ordinary Reflector .	14	21	40	7	10	0	5	15	46
In the Scotch Revolving Reflector.	ditto.			ditto.			4	9	48

Mr. Thomas Stevenson places a lenticular front upon the parabolic mirror, Fig. 5, so as to condense the cone of light which would otherwise pass off in its natural state of divergence; and in place of the corresponding back portion of the reflector, he substitutes a spherical metallic mirror, which returns the flame upon itself, though inverted.

Let it be assumed that, with this modification of Mr. Stevenson, the proportion of the luminous sphere, which the parabolic mirror and its adjuncts condense, is equal to that which is embraced by a complete dioptric instrument; still the defect of wasteful divergence remains.

There is a practical limit to the dimensions of the reflector; and perhaps it would be found inexpedient to extend the size beyond that of the Scotch instrument, whose aperture has a diameter of 25 inches.

If, again, with a given maximum size of reflector the diameter of the burner be enlarged without the introduction of a further wick, there will be a corresponding increment in the divergence of the beam, but very little, if indeed any, addition to its mean intensity.

There may be a slight increase in the intensity of the flame itself, arising from the more active combustion which accompanies increased heat; but this advantage will be small in amount. And even if a further wick be introduced, the proportionate increment of mean intensity will be much below that of the consumption of oil.

In order, therefore, to obtain an intensity of illuminating power at all approaching that of a dioptric instrument of the higher orders, there is no resource but to multiply the number of the separate reflectors.

For the purpose of estimating the exact multiplication of reflectors which would be required, recourse must be had to experiment; but unfortunately in this kingdom there is no national institution corresponding to the 'Etablissement Central des Phares' at Paris; and hence for experimental statistics in this matter the results obtained in France must be consulted. M. Léonor Fresnel, in his communication dated the 31st December, 1845, to the Lighthouse Board of the United States, drew up an elaborate account of the comparative advantages of the system of metallic reflectors and dioptric instruments for sea-lights. Those results, however, require to be revised, in consequence of the improvements which have been effected in the Fresnel system since that date; and, accordingly, more reliable figures of comparison may be met with in later publications emanating from the French Lighthouse Engineers. In the Mémoire of M. Reynaud will be found a very complete comparison, based upon actual photometrical observations, of the relative economical and useful merits of the two rival systems of metallic reflectors and dioptric instruments.

M. Reynaud shows that a Fresnel light of the fixed kind, even of the second order, can be equalled by reflectors only by multiplying them to the number of 60, each giving about the same quantity of light in the horizontal plane as the English[1] reflector; and that the consumption of oil will be seven times more in the employment of these reflectors than in the case of the dioptric apparatus. In England, a fixed light of reflectors has them generally in the proportion of 24 to 27 in number for 360°. A first-order fixed Fresnel light gives nearly double[2] the intensity of that of a second-order one; and, accordingly, to rival this apparatus, the number of the reflectors must be about 108: but this is, of course, purely an imaginary structure. Yet, even with all this multiplying of reflectors, the perfection of uniformity in the distribution of light over the horizon, which accompanies the fixed dioptric light, cannot be imitated by parabolic mirrors.

From the foregoing estimate of the number of reflectors required for an apparatus which would be equal in power and general effect to a first-order dioptric fixed light, it may be calculated approximately what arrangement of reflectors would be necessary, in order to produce the effect of a first-order dioptric revolving apparatus.

Let it be supposed, for example, that this light has eight sides, and that the axes of the upper, middle, and lowest panels respectively, have slightly different directions in azimuth, so that the horizontal divergence shall be one-half of that of the reflectors; then,

[1] Allowance being made for the larger diameter of the French burner employed in these experiments, as compared with that of the English one.—J. T. C.

[2] The ratio is that of 630 to 335 according to the French experiments.—J. T. C.

the catoptric apparatus should consist of four sides, each of which should carry twenty-seven reflectors of the English size.

One point of advantage in the dioptric apparatus should not be forgotten. No one can visit a light consisting of reflectors without finding some of them out of adjustment, in relation to the position of the burner, or the direction of the axis of the paraboloid. Indeed, in a revolving light, it is a matter of no little nicety to place, and to keep permanently in due parallelism, all the axes of the reflectors which have to co-operate together on the same face of the frame. Whereas, in a dioptric light, the optical apparatus itself is adjusted irremovably, once for all; and the only deviation which can take place in the position of the burner is on the occasion of changing it; but the provision for indicating its due adjustment in every respect is so simple and unalterable, that nothing but the most wilful neglect can produce any error.

Catadioptric, or Totally-reflecting, Spherical Mirror.

Until late years, the metallic spherical reflector was the only resource for returning the back hemisphere of rays, or a portion of it, upon its luminous source. Just, however, as the metallic surface of the paraboloid has been condemned, that of the spherical reflector is similarly objectionable. But it has another serious defect: the reflected flame has an inverted position; so that either the chief portion of the reflected rays must fall upon the burner, or else the focus of the reflector must be raised so far above the burner, that the main reflected light, when transmitted by the dioptric instrument in front, falls far within the sea-horizon direction: the latter alternative, however, although not satisfactory generally, should be adopted.

And here it is well to remark, that many metallic reflectors, now useless in some British lighthouses, might be made available, as far as their limited capabilities extend, by readjusting the focus in relation to the burner.

Fortunately, however, the metallic spherical reflector has been superseded, for sea-lights, by the catadioptric one, which was originated by Mr. Thomas Stevenson, and may be thus described.

Figure 6 represents the sections which, by revolving round the axis of the flame, generate the totally-reflecting mirror, and shows to scale the instrument which is used in the larger sea-lights; the dimensions being reduced for the smaller apparatus.

The inner surfaces are zones of spheres which have a common centre, F, in the axis of the flame, at the centre of its effective portion. They constitute a perfect spherical mirror for that faint amount of light which is superficially reflected. The characteristic feature, however, of the instrument is that which concerns the main portion of incident rays which enters these inner surfaces.

Let the two outer sides of any generating section be supposed to be parabolic arcs, A B and A C (Fig. 7), having a common parameter, A F: a ray, F P incident at P, beyond the critical angle, is totally reflected in a path which is perpendicular to the parameter, and meeting the other arc at Q, is again totally reflected in the direction Q F. The parametral ray F A is reflected along A F. By the property of the parabola, the angle of incidence of F A at A is 45°, and that of F P at P is $\left(45° - \frac{AFP}{2}\right)$. Hence at either extremity, as at B, $\left(45° - \frac{AFB}{2}\right)$ must not be less than $\sin^{-1}\frac{1}{\mu}$, where μ is the refractive index of the least refrangible ray of the spectrum. This condition determines the maximum value of A F B, supposing the radiant body to be a point. Consider, however, the angle F B H subtended by the flame on the side of F B, where the normal at B is situated: the angle of internal incidence of H B at B is $\left(45° - \frac{AFB}{2} - \sin^{-1}\frac{\sin FBH}{\mu}\right)$, and this angle must not be less than $\sin^{-1}\frac{1}{\mu}$ from which condition the maximum value of A F B, corresponding to F B H, is obtained.

Similarly, the maximum value of A F C can be found: but the limit of B F C is taken as twice the lesser angle, otherwise the section would not be symmetrical.

In the actual execution of the zone, each of the arcs A B, A C, is circular: the radius at A coincides with the normal at that point to the parabolic arc, and the radius at the extremity is parallel to the normal to the parabolic arc at its extremity. Therefore the angular positions of these two radii are known; and hence the coordinates of the centre of curvature and the radius are determined.

The image of the flame will coincide with the original, except that it will be simply turned half round the vertical axis.

A full mathematical investigation, by Professor Swan, will be found in the Appendix to the Treatise of Mr. Thomas Stevenson. But it will be perceived that the zones are supposed to be generated round a horizontal axis. The image will alternately pass from its erect position to an inverted one, and conversely through the successive quadrants, beginning at the highest or lowest points of the mirror.

The vertical arrangement of the zones not only presents difficulties of execution, but also does not permit the mirror to be so readily restricted within any desired limits in altitude, as if they are horizontal.

The plan of generating the zones round the vertical axis was introduced by the Author, who adopted it in the first complete catadioptric mirror which was made, and which was shown in the Exhibition of 1862 by the Commissioners of Northern Lights, for whom it was constructed, in order to further the realizing of what Mr. Thomas Stevenson had ingeniously suggested about twelve years previously.

During the progress of this instrument, the idea occurred to the Author of separating the zones, and also of dividing them into segments, like the ordinary reflecting zones of a dioptric light: by this means it became practicable to increase considerably the radius of the mirror, and thereby to render it applicable to the largest sea-light, without overstepping the limits of the angular breadths of the zones, and yet without being compelled to resort to glass of high refractive power.

The separation of the zones also rendered it feasible to avoid giving to the aggregate structure a spherical shape, which would have encroached most inconveniently upon the space required for the service of the lamp.

This improvement was carried into effect towards the end of 1862; and early in 1863 two mirrors were constructed for Messrs. Stevenson, as accessories to two fixed sea-lights intended for the coast of Otago, New Zealand: one being a first-order apparatus for Cape Saunders, the other a third-order light for Tairoas Head.

The same types have been retained unchanged to the present time, and have been used extensively both in fixed and in revolving lights.

Mr. Thomas Stevenson's Azimuthal Condensing System.

A valuable feature in the dioptric apparatus is its ready adaptability to special requirements. Take the case in which a fixed light, of a given power, has to illuminate a portion only of the azimuthal circle, but where in one or more directions greater intensity is wanted. Mr. Thomas Stevenson solved a problem of this kind at Isle Oronsay in October, 1857. Rather less than a semicircle had to be lighted; but two small portions of the illuminated sector, one on either side, required a power much exceeding that of the rest of it. The landward residue of the 360° was accordingly divided into two suitable parts, each of which was made to transmit its light in a series of angles parallel to the corresponding angles whose illumination required to be intensified. Without this arrangement a number of separate reflectors and lamps must have been used for the purpose. A full account of this light will be found in Mr. Thomas Stevenson's Treatise, already alluded to. The horizontal deflection in a case of this kind is effected by vertical reflecting or refracting prisms. The apparatus at Oronsay was one of the smaller order.[1] The Author, however, applied a similar method to a first-order apparatus at Great Orme's Head, in 1862, for the Mersey Docks and Harbour Board, and subsequently at Gibraltar for the Trinity Board, in each of which lights there was a spare arc, and increased power was required in a particular sector of the sea-surface for the purpose of strengthening a red beam. In each case a group of vertical prisms is fixed outside the spare arc, whose light is thus utilized, consisting of three tiers, which correspond respectively to the refracting and the two reflecting divisions of the instrument, and having, in all, a height of about 9 feet. The design for Gibraltar (Fig. 8) demanded more contrivance than that for Great Orme's Head. One chief point was, to avoid excessive obliquity of incidence on the lantern panes: for this, and other reasons, the reflecting prisms, R, were made to act together as a single cylindrical concave mirror, which brought the rays into an approximate focus, from which they diverged in the required directions. This concave grouping of the vertical deflectors, provided a most convenient space for the introduction of a single parallelizing vertical prism, P, which would send a strong beam along the intended boundary of the red arc. A screen of red glass, S, was situated between the main apparatus and the accessory upright prisms. As each tier of prisms would, if fixed in their frames, be liable to accident while being transferred and erected in their places; but as, on the other hand, it was absolutely essential that the final adjustment of these vertical prisms should be an accurate imitation of what had been originally performed in the first construction, every vertical prism was transported apart from its frame: but, previously to its removal, brass templates were fitted with the greatest exactitude, to indicate the precise due position of each prism. What was finally carried into effect at the destination of the apparatus was, accordingly, an exact reproduction of what had been done at the manufactory, with the nautical chart as a guide.

From these examples it will be evident, that subsidiary parabolic reflectors are not required generally for the purpose of intensifying the light in particular arcs. On the contrary, reflectors are objectionable, inasmuch as they are not suitable for defining sharply the due confines of an arc. For even if the natural radiation in front of the reflector be condensed, as by Mr. Thomas Stevenson's anterior lens, yet, since the divergence of the reflected light increases from the edge of the mirror towards its vertex, or to the centre of the front lens, the inner conical beams cross the outer

[1] The Author designed an apparatus for Dartmouth Harbour (Fig. 10), for Mr. R. P. Brereton, M. Inst. C.E., in which two arcs of red and green light respectively were strongly intensified by vertical reflecting prisms.—J. T. C.

ones, and produce a penumbral light, increasing in faintness outwards, which is spread over a large angle on either side of the arc requiring illumination, and which it is generally inconvenient to intercept effectively, if indeed practicable.

Hence this system of illuminating particular arcs is in every respect advantageous. It need scarcely be added, as a mere corollary of what precedes, that for leading lights the dioptric azimuthal system is peculiarly suitable. The Author some years ago designed two for Hoylake on this principle, for the Mersey Docks and Harbour Board; and he has lately constructed two according to Mr. Thomas Stevenson's design for Buddonness, at the entrance of the Frith of Tay.

In both cases a fixed apparatus of 180° of the ordinary kind is employed; and vertical prisms, which deflect horizontally, are placed in the complement of each half of the illuminated angle, and distribute over it equably their respective diverging beams.

To the Buddonness apparatus (Fig. 9), however, Mr. Stevenson has added some ingenious arrangements, by which the chief portion of the back hemisphere is sent forward, and uniformly spread over the illuminated sea-sector. The equatorial belt of about 60°, or one-half of the back light, is returned upon itself by the totally-reflecting mirrors already described; but the novelty consists in dealing with the half cone of light which diverges above this mirror. It is first condensed cylindrically by a compound semi-lens, and then deflected horizontally, as well as uniformly expanded over the illuminated direct arc, by means of a series of right-angled prisms, in circular segments, placed above the rest of the apparatus. The curvature of these segments, which should be convex outwards, ought to increase from the foremost in succession backwards, in proportion to the diminution of the section of the vertical beam which each acts upon.

The spherical mirror is made to open by hinges, in order to give access to the interior of the apparatus.

The fixed light has a diameter of $29\frac{1}{2}$ inches; and the height of the apparatus, exclusive of the upper reflectors, is 4 feet.

A full-sized model of this instrument is now at the Paris Exhibition. It is especially interesting, as combining every existing dioptric method employed in lighthouses.

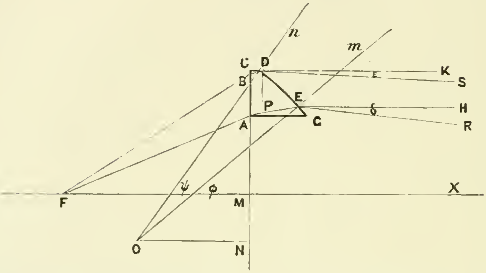
In the Appendix will be found the mathematical investigation of the various problems referred to in this communication, which is also accompanied by a series of diagrams from which Plate 15, and woodcuts, Figs. 1 to 5, have been compiled.

[APPENDIX.

APPENDIX.

Generating Section of a Refracting Zone, or Straight Prism.

Fig. 1.



A C D G is the section : F a radiant point. F X is perpendicular to the side C A produced ; the section being plano-convex.

Let F A E R, F B D S, be the extreme rays, making with F X the angles δ, ϵ, respectively, on emerging : D K and E H being parallel to F X.

O E m, O D n, are normals at E and D, to the convex side D G, which is circular, so that O E, O D, are radii of it: let them make with F X the respective angles ϕ and ψ.

Let α and ρ be the angles of incidence and refraction at A ; β and σ those at B :

$$FM = f,\ CD = t,\ AC = b = f\,.\,\tan\beta - \tan\alpha + t\,.\,\tan\sigma.$$

Then,
$$\sin\rho = \frac{\sin\alpha}{\mu},\ \sin\sigma = \frac{\sin\beta}{\mu}.$$

The angle of incidence at $E = \phi - \rho$

" " " $D = \psi - \sigma$;

$$\sin(\phi + \delta) = \mu\sin(\phi - \rho) \text{ and } \sin(\psi + \epsilon) = \mu\sin(\psi - \sigma).$$

Therefore,
$$\tan(\phi + \delta) = \frac{\mu\sin(\rho + \delta)}{\mu\cos(\rho + \delta) - 1},$$

$$\tan(\psi + \epsilon) = \frac{\mu\sin(\sigma + \epsilon)}{\mu\cos(\sigma + \epsilon) - 1};$$

whence ϕ and ψ are determined.

Draw D P parallel to C A intersecting A E at P, then in the triangle D E P, the

$$\text{chord } DE = DP\,.\,\frac{\cos\rho}{\cos\left(\dfrac{\phi + \psi}{2} - \rho\right)};$$

where
$$DP = b - t\,.\,\tan\rho.$$

Therefore, if r = radius of curvature of the arc D G,

$$r = \frac{DE}{2}\,.\,\frac{1}{\sin\dfrac{\psi - \phi}{2}},$$

$$= \frac{(b - t\,.\,\tan\rho)\,.\,\cos\rho}{2\sin\dfrac{\psi - \phi}{2}\cos\left(\dfrac{\psi + \phi}{2} - \rho\right)};$$

and, for the co-ordinates of O, referred to M as the origin,

$$ON = r\cos\psi - t, \text{ and } NM = r\sin\psi - f\tan\beta - t\,.\,\tan\sigma.$$

I. If the section be required for a prism, which is detached, $t = o$ generally.

II. If the emerging rays be parallel to each other, $\delta = \epsilon$; and if they are parallel to the axis F X, $\delta = o$ and $\epsilon = o$, as in the ordinary section of Fresnel.

III. If either emerging ray pass between the normal at the point of emergence and the axial direction, the corresponding angle δ, or ϵ, will be negative.

IV. If F A be perpendicular to C A, $\alpha = o$, $\rho = o$.

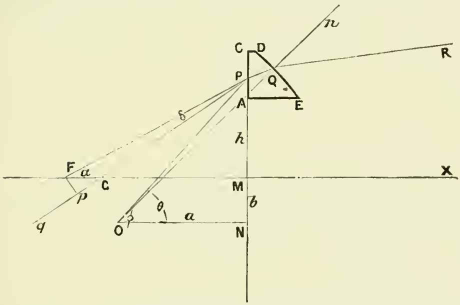
V. If the joints of the zones are inclined, in the directions of the refracted rays, the foregoing formulæ will remain the same; the angles of glass E A G and C D B being removed, so that the actual section will become A B D E.

VI. If C A be a circular arc, either concave or convex, the angles of incidence will be changed accordingly; again, the side of emergence may be made concave instead of convex, in which case $\psi - \phi$ becomes negative, and r is negative; but the plano-convex form is that which circumstances most generally require.

VII. By commencing from the point C or the point B in the same way as that adopted in the foregoing problem, the sections of the successive zones may be similarly calculated for the Fresnel lens or cylindrical refractor.

To Determine the Path of any Ray.

Fig. 2.



Let A C D E be a generating section, as determined by the preceding problem for the extreme rays from a given radiant point F.

Let any ray q P, crossing the axis at G, be incident upon a point P of the lens, and describe the path P Q R.

Draw Fp perpendicular to qP: join O P, and O Q which produce to n : n Q R is the angle of emergence.

Let $\quad$ O N $= a$, N M $= b$, M P $= h$, O Q $= r$,

P F M $= \alpha$, F P G $= \delta$, F M $= f$, Fp $= d$,

P O N $= \theta$, Q O N $= \phi$,

the angle of refraction of q P at P $= \rho$,

the angle of emergence of P Q at Q $= \eta$.

Then $\sin\delta = \dfrac{d}{f}\cdot\cos\alpha$, and $\sin\rho = \dfrac{\sin(\alpha+\delta)}{\mu}$, $\tan\theta = \dfrac{b+h}{a}$,

and in the triangle P O Q, $\sin(\phi-\rho) = \dfrac{\mathrm{OP}}{\mathrm{OQ}}\sin(\theta-\rho)$,

$$= \frac{a}{r}\cdot\frac{\sin(\theta-\rho)}{\cos\theta} \qquad (1);$$

also, $\quad \sin\eta = \mu\sin(\phi-\rho) \qquad (2);$

whence ϕ and η are determinable; and $(\phi - \eta)$, which is the angle made by the emerging ray Q R with the axis F X.

I. If the incident ray cross the axis beyond F, δ is negative.

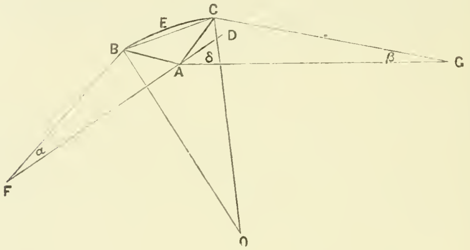
II. If $\delta = o$, we have the paths of the *focal* rays at the successive points of the lens.

III. If $(\phi - \eta)$ be negative, the ray Q R crosses the axis F X on the outer side of the refracting section.

IV. From the triangle P O Q is obtained the length of the path P Q for any ray in its passage through the glass.

Totally-reflecting Prism.

Fig. 3.



A B C is the generating section of a totally reflecting prism, upon which is incident in the plane of the section the angle of light A F B from the radiant point F.

Let A G and C G be the directions of the extreme emerging rays.

Let A F B = α, A G C = β, the angle of incidence of F A at A = θ; produce F A to D and let D A G = δ.

In order to avoid superfluous glass, the sides A B and A C are made to coincide with the paths of the rays F B and F A: hence the angles B A F and C A G are equal to each other; and

$$\text{B A C} = \frac{\pi}{2} + \sin^{-1}\left(\frac{\sin\theta}{\mu}\right).$$

Therefore, $$2\left(\frac{\pi}{2} - \theta\right) + \frac{\pi}{2} + \sin^{-1}\left(\frac{\sin\theta}{\mu}\right) = \pi + \delta,$$

$$\sin\theta = \mu\sin\left(2\,\theta + \delta - \frac{\pi}{2}\right),$$

from which equation θ can be found tentatively.

Let ρ, ϕ, ψ be the angles of refraction at A, B, and of internal incidence of the emerging ray C G, respectively.

$$\text{Sin}\,\rho = \frac{\sin\theta}{\mu},\ \sin\phi = \frac{\sin(\theta - \alpha)}{\mu},\ \sin\psi = \frac{\sin(\theta - \beta)}{\mu}.$$

Draw at B and C the radii B O, C O, of the circular arc B E C which is the reflecting boundary of the prism; and draw the straight line B C.

$$\text{A B O} = \frac{1}{2}\left(\frac{\pi}{2} + \phi\right),\ \text{A C O} = \frac{1}{2}\left(\frac{\pi}{2} + \psi\right).$$

The angle B O C = B A C − (A B O + A C O).

Therefore, $$B\,O\,C = \rho - \frac{\phi + \psi}{2},$$

and as B C is circular, $$O\,B\,C = O\,C\,B = \frac{\pi}{2} - \frac{1}{2}\left(\rho - \frac{\phi + \psi}{2}\right).$$

Therefore, $$A\,B\,C = O\,B\,C - A\,B\,O = \frac{\pi}{4} + \frac{\psi}{4} - \frac{\rho}{2} - \frac{\phi}{4},$$

$$A\,C\,B = O\,C\,B - A\,C\,O = \frac{\pi}{4} + \frac{\phi}{4} - \frac{\rho}{2} - \frac{\psi}{4}.$$

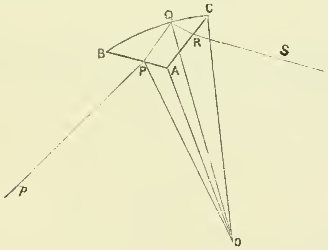
Let $F\,A = f$, then $A\,B = f \,.\, \frac{\sin \alpha}{\cos(\theta - \alpha)}$, $\quad A\,C = A\,B \,.\, \frac{\sin A\,B\,C}{\sin A\,C\,B}$,

chord $B\,C = A\,B \,.\, \frac{\sin B\,A\,C}{\sin A\,C\,B}$, and radius of curvature $= \frac{B\,C}{2} \,.\, \frac{1}{\sin\left(\frac{B\,O\,C}{2}\right)}$.

If the emerging rays be parallel, $\beta = o$, and $\psi = \rho$.
If the emerging rays be diverging, β is negative.
In order to facilitate the construction of the prism, the points B and C, and the centre of curvature of B E C, are referred to axes of co-ordinates, which may be chosen as may be most convenient in practice.

To Determine the Path of any Ray.

Fig. 4.



Let p P Q R S be any ray.
O is the centre of curvature of the reflecting side B C.
Join O P, O A, O Q, O C.

In the triangle A C O, the two sides A C, C O, and the included angle at C, are known:

hence from the equations, $$\tan \frac{1}{2}(C\,A\,O - A\,O\,C) = \frac{C\,O - C\,A}{C\,O + C\,A} \cot \frac{A\,C\,O}{2},$$

and $$C\,A\,O + A\,O\,C = \pi - A\,C\,O,$$

are determined C A O, and A O C: hence A O is obtained.

Again, in the triangle A P O, P A is given, A O has been determined, and $P\,A\,O = 2\pi - (B\,A\,C + C\,A\,O)$; hence, as in the previous case, A P O and P O are found.

Now as the direction of p P is given, the angle Q P A is known; hence in the triangle P Q O we have P Q O from the equation

$$\sin PQO = \frac{OP}{OQ} \cdot \sin QPO,$$

and $$PQR = 2\,PQO,$$

$$QRA = 2\pi - (QPA + BAC + PQR),$$

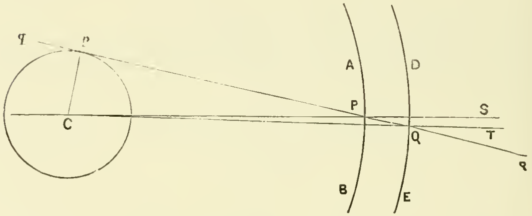
and $$\cos CRS = \mu \cos QRA;$$

whence is obtained the direction of R S the emerging ray.

The length of the path P Q, Q R, of the ray through the prism is also obtained.

THE APPARENT DIAMETER OF THE FLAME IN THE FOCAL PLANE OF A FIXED APPARATUS IS NOT CHANGED BY THE INTERPOSITION OF THE REFRACTING ZONE.

Fig. 5.



A B E D is a segment of a horizontal section of a lenticular zone generated round a vertical axis through C. Let a ray of light q P in this section be incident at P and take the path P Q R. Join C P and C Q; draw C p perpendicular to q P; and produce C P and C Q to S and T respectively.

In the triangle P C Q, $\sin PQC = \frac{CP}{CQ} \sin QPS$;

therefore, $$\sin TQR = \mu \sin PQC = \frac{CP}{CQ} \mu \sin QPS$$

$$= \frac{CP \sin qPC}{CQ} = \frac{Cp}{CQ};$$

hence if R Q the emerging ray be produced, it will touch the circle described round C with the radius C p.

Mr. Gregory, Vice-President, said, the applause of the meeting had already anticipated the cordial vote of thanks which he was sure every one would accord to Mr. Chance for this valuable Paper—a Paper which would be a most useful addition to the archives of the Institution, and would derive additional interest from the fact of the Author having brought his attainments in exact science to bear upon his well-known practical knowledge as a manufacturer. As a juror at the Paris Exhibition, his attention had been called to some of the results of Mr. Chance's labours, to which the Paper had so modestly referred. The apparatus exhibited by the Trinity House and by the Commissioners of Northern Lights, to the excellence of which Mr. Chance had materially contributed, excited the admiration of his brother jurors, and particularly of M. Reynaud, the distinguished Engineer at the head of the Lighthouse Department of France, and were felt by all to do credit to this country.

Mr. Chance said, it was only right he should mention, that the idea of presenting a Paper to this Institution upon a subject of so much importance did not originate with himself. It had, however, afforded him the greatest pleasure, which was enhanced by finding that the communication was regarded as in any way useful to the Institution. By way of explanation, it was important to add, what no doubt had been already perceived, that the purely optical part only of the subject had been dealt with; and that the Paper did not pretend to give a complete view of this branch of engineering. There were several mechanical considerations in the structure of the apparatus, in order to give the optical part the greatest possible effect, and also for producing in the best manner the movements required, whether in the rotation of the main apparatus or in providing the overflow of oil, to which allusion had been made. He had not treated of these, and if any one would do so, it would add greatly to the interest of what he had written. There was also the nautical engineering connected with the subject, which he hoped some one would take up. The main object of the particular form which he had given to this Paper had been to present, as truthfully as possible, the history of the invention itself. Although most admirable treatises had appeared, yet there were few who would go through them carefully, or if they did do so, would have time to glean from them the actual facts which constituted the history of this particular department of science. This was the first occasion, he believed, on which this particular subject had been presented for discussion at the Institution; and he should be glad if, in the course of the discussion, any errors into which he had inadvertently fallen were pointed out.

The Astronomer-Royal said, his practical acquaintance with lighthouses (though he had seen many in a cursory way) began, not as a member of the Royal Commission, but from having been occasionally invited in a friendly way by the Chairman to assist in the examination of the British lighthouses. One point to which Mr. Chance had especially alluded had pressed itself upon his notice, and, no doubt, upon the members of the Commission, viz., that in looking at lighthouses the way to examine accurately their performances was not to look outside but inside. This did not come upon him in full force till he went, accompanied by a member of his family, to look at the Whitby lighthouses, which were pointed out by Mr. Chance as presenting the best instances of British manufacture of the optical apparatus. The moment, however, he came to look at the thing himself, and to have the whole judgment of it himself, he looked a great deal sharper into it than he did before; and he attached great importance to this, for this practical reason, that he did not think the personal organization of the English system of superintendence of lighthouses was good—that of the Scotch system was admirable. However, when he came to take the internal view of things as they presented themselves at the Whitby lighthouses, he saw, to his great astonishment, that the larger portion of the light must be lost. He pointed this out to his companion, who saw as he did; and, what was more remarkable, the attendant on the lights saw it as well. He mentioned that, to show how easy it was to see this great defect in the action of lighthouses, and how curious it was that it should have escaped observation up to that time. The result was, that there was an assembly of persons from several departments at the Whitby lighthouses: the matter was discussed; and he trusted these particular observations, to which Mr. Chance attached some importance, had been of benefit in the subsequent arrangements of lighthouses. He hoped they might operate also in another way, that was, in making an alteration in the personal organization of the superintendence of lighthouses.

He would express his great thanks to Mr. Chance, for giving the history of lighthouses just at the time when a perfect history could be made from the beginning, and especially when the practical question was just in the state for its history to be given. With reference to the shape of the lenses, he might state that at one of the lighthouses—he thought it was the Start—in viewing the formation of an image by the different zones of the dioptric part of the light (as in Fig. 2, Plate 15), it struck him that they must have been ground in the manner in which an optician ground a lens. Everybody knew how convex glasses of any kind were ground in a bowl, and in that way a perfect, but only a spherical shape could be given. It struck him that these different zones must have been all ground in one bowl; and Mr. Chance was good enough to get a note from the man who worked them, which supported that view. The effect of grinding in a bowl in that way was this—that too great a curvature was given to the cross section of the rings of the lens exterior to the centre. He had had the advantage of seeing the beautiful mechanism in Messrs. Chance's works, and that which struck him most was the cross-stroke in the polishing; when there was a ring lens to be made, the cross curvature was not given by grinding in a bowl, but by the cross-work of the polisher; and by some small adjustment of the mechanism, which Mr. Chance had arranged, there was a power of altering the degree of curvature which would be given by that cross-stroke. Upon that everything depended, and he looked upon it as the critical point in the construction of these lighthouses. Now he thought he might say, from what he had observed, that the care in grinding these surfaces had migrated in some measure from its first country to its second. Looking at Mr. Chance's testing methods, he had no doubt that every ring-lens which came from his manufactory was as perfect in its action as it was possible to make anything. Some time ago he examined one of the British lighthouses erected at Paris, and he had no hesitation in saying, the lower reflecting prisms had not been tested in the way practised by Mr. Chance. He had arrived at that conclusion because, when the light diverged from a lamp and fell upon the prisms, the intention was that it should emerge in parallel beams with reference to the vertical plane. Then it was perfectly understood from that, as a matter of optical theory, that the converse proposition held, viz., that if parallel rays came from an object at a very great distance and fell upon these curves, they would converge at the place of the lamp; and that was the foundation of the method of testing to which Mr. Chance alluded, and of which he had spoken in reference to the Whitby lights. In the lighthouse he referred to, which was manufactured for a British lighthouse, and was maintained at the expense of the Trinity Board, he found that the image of the horizon, or that of ships at a distance, was not formed near the lamp, but at about two-thirds the distance between the prisms and the lamp. He need not say that in such a case a large proportion of the light which diverged from the lamp and fell upon the prisms, after refraction by the prisms, diverged ultimately at so large an angle, that it could have only a very slight effect. To this he bore his testimony, and he mentioned, in consequence, his conviction that these points were looked to more carefully in England at this time than in France. There was another point of experience to which he would advert, and he mentioned it as a thing of which he could not give an explanation, because he had not severely examined the dioptric lighthouse concerned. There were two lights at the South Foreland, which could be seen nearly across the whole breadth of the Channel; and he had himself seen them from the gallery of the Calais lighthouse. One of these was a dioptric light, and in the other the old parabolic reflectors were used. On one occasion, crossing the Channel at night, the air being in magnificent condition for observation, he employed himself in steadily looking at, and in comparing the intensity of, those two lights, all the way till he got near Calais. Sometimes he thought one was the better and sometimes the other. He would say, after the pains taken in the general manufacture of the dioptric light, he expected that it would blaze out beyond the other all the way; but the old reflector light was sensibly as good as the new one. From what cause it arose he could not say, for he had not severely examined that lighthouse. In justice to Mr. Stevenson he would now say in words what he had said in print. He had examined a good many lighthouses in England, France, and Scotland, and the best he had seen were the Scotch lighthouses.

Mr. Thomas Stevenson said, after the clear and able Paper by Mr. Chance, he was not aware that there was much, or anything, left for him to say. He begged to thank the Astronomer-Royal for the flattering manner in which he had spoken of the labours of himself and other members of his family.

As to the dioptric spherical mirror, he might say, without derogating from Mr. Chance's merit in the matter, that his (Mr. Stevenson's) first idea was to make it by generating prisms round a vertical axis, but at that time flint glass could not be obtained in large pots. It required to be taken out in very small quantities on the end of a rod, and to be pressed down into the mould. Therefore he was obliged to reduce the diameter of the rings as much as possible; and it was thought by all whom he consulted at the time, as well as by himself, that by generating prisms round a horizontal axis, the more important parts of the instrument would be more easily executed, inasmuch as the prisms at and near the horizontal axis were of much smaller diameter. He mentioned this as an excuse for not having adopted the form shown in the drawing, which was certainly better. Mr. Chance had, however, not only chosen the best form, but had added the important improvements of separating the prisms and arranging them in segments. There was just one other point as to which he would make a remark. The most simple form of holophote was that shown in Figs. 6 and 7, page 37, which was described in his book on Harbours. It consisted of a half-holophote, *a b c*, which operated upon 180° of the flame in front, beyond which angle total reflection could not be carried, with glass of ordinary refractive power. Then, instead of having a spherical mirror, subtending the remaining 180°, it was preferable to have a portion of a paraboloid

($e\ h$, $f\ i$), so that the rays were sent forward parallel at once; whereas if the spherical mirror had subtended 180°, a large portion

Fig. 6.

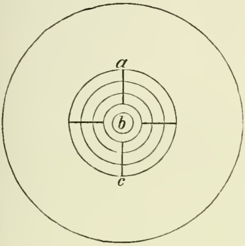
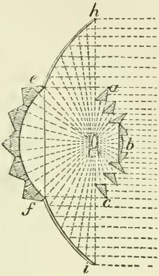


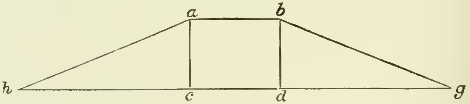
Fig. 7.



of the rays would have been lost on the burner; and again, all the back rays would have been subjected to the action of more than one agent, whereas by the one paraboloidal agent the incident rays were at once parallelized, and the remaining rays were reflected back through the flame by the dioptric spherical mirror ($e\ f$). The same might be effected by the use of two refracting and totally reflecting agents of glass; but the one paraboloidal agent was less complicated and nearly as efficient. It thus appeared that the most simple form of holophote was that in which both glass and metal were employed.

Colonel SMITH said, he would not have ventured to make any remarks were it not that he thought it undesirable a Paper such as this should go forth without comment. He believed any person who studied the Paper would arrive at the conclusion, that the Author was of opinion that the catoptric system of lighting was so obsolete and out of date, that the sooner it was got rid of the better. He was not an advocate of that system in opposition to the dioptric, because he was a great admirer of the latter; but it was one thing to admire a highly scientific arrangement, which on some occasions was by far the most useful; and another to put aside, repudiate, and discharge with contempt, a system which had proved valuable for so long a time. He had only read the abstract of the Paper in a hasty manner; but the conclusion he arrived at, amongst other things, was that there were about an equal number of lights on the catoptric and on the dioptric systems respectively on the British coasts; and he imagined the opinion of the Author to be, that it was a pity not to get rid of all the old-fashioned apparatus, and substitute the new one in all lighthouses. But he thought the catoptric apparatus, though inferior in scientific arrangement and in its effects to the dioptric, had many advantages, which must not be lost sight of, especially with regard to the colonies. He considered a little undue prejudice had been given to the catoptric system by the remarks contained in the admirable work of Mr. Alan Stevenson, published about eighteen years ago; in which it was pointed out, with regard to both fixed and revolving lights, that the dioptric arrangement was superior to the catoptric in the ratio of 3 or 4 to 1. He had no doubt that was correct; but then Mr. Stevenson took the maximum illuminating power of each apparatus, and omitted all the rest. In regard to the lens, the maximum illuminating power was nearly the whole of it, and one of the drawbacks to the lens system was the very short duration and great power of the flash. In fact, the whole power was concentrated into a cone of 5° opening; but the reflecting or catoptric system was very different. It formed a cone of light, according to the Trinity House arrangement, of more than 19° opening; and comparing merely the maximum power of that reflector—and that was only 4°—and leaving out the 15°, justice was not quite done to it. There were arrangements which might be made for the equalization of the effects of the light, and full justice was not done to the system if they were omitted. Fig. 8 represented the whole useful effects of the para-

Fig. 8.



bolic reflector, the heights *a c*, *b d* at various points representing the amount of illumination. Here it would be observed that the figure *a b*, *c d* represented the maximum effect of a parabolic reflector which was perfectly uniform from *a* to *b*; *a h* to *b g* represented the increasing and diminishing effects before and after the maximum.

With respect to the irregularity of effect in fixed lights on the catoptric system, mentioned in the Paper and in Mr. Alan Stevenson's book, it was quite true it was irregular, although not so much as was made out, but this irregularity could be in a great measure corrected. If, in Fig. 9, *a b f* and *d e k l* represented the effects produced by two adjoining reflectors, then the triangle *b d f* would show the declining light of one, and *e f d* the increasing light of the other. He must, for the present, assume these to be true triangles; and granting this, if two of these reflecting systems were joined together, so that one triangle overlapped the other (as $b\,d\,f$ and $e\,f\,d$), it did not require demonstration to show, that the quantity of light added by the triangle $d\ h\ i$ was equal to the quantity of light missing in the triangle $b\ h\ g$; consequently the whole effect of the two combined reflectors would be perfectly uniform.

That would be true if the spaces $b\,d\,f$ and $e\,f\,d$, representing the increasing and diminishing effects of the light were true triangles; but they were not so, being rounded by curves at $b\,f$ and $d\ e$. The consequence was, the overlapping of these figures did not produce an exact regularity in the light, but it was sufficient for all practical purposes. The real objection, in his opinion, to the catoptric light, compared with the dioptric, was reduced to a matter of pounds, shillings, and pence. If as many reflectors could be put side by side around the horizon as would make up a nearly equal distribution, forty-five Trinity House reflectors would be required, which would involve considerable cost, and the quantity of oil consumed would be three times as much as was consumed by one of the Fresnel dioptric zones, to produce the same effect. Supposing the whole circle of the horizon were illuminated, the result would be, as he had just stated, 3 to 1 in favour of the zones; but if only half the horizon had to be illuminated, the central lamp was still required in the dioptric system, and that involved the whole 570 gallons of oil consumption. With the reflectors only 22 might be worked, and half the expense be got rid of. If less than the half-circle were to be illuminated, a smaller number of reflectors would be required. That was one respect in which there was advantage in the use of reflectors.

Again, in the dioptric system, although the central lamp illuminated the whole horizon, yet if anything happened to that light, the whole horizon was in darkness. With reflectors, forty-five or twenty-two lights were required to fill the whole or half the circumference of the horizon, and if one light went out only a 45th part of the horizon was in darkness. However, he was obliged to admit this system was not

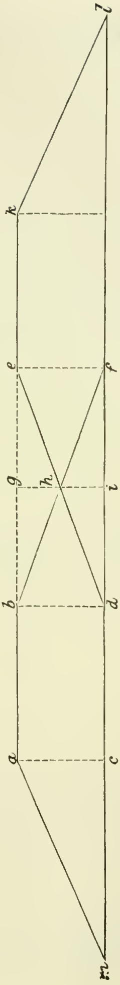
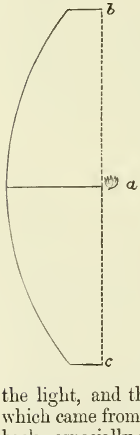


Fig. 9.

absolutely perfect; with all the arrangements that could be made, and with forty-five reflectors, an absolutely perfect light was not obtained; nevertheless he maintained, in opposition to the Author of the Paper, and to what had been previously published, that by other means on the catoptric system it was possible to produce absolute uniformity of distribution, and an equally good effect by reflectors as by zones.

One of the figures exhibited by the Author represented, it was said, a section of one of the lenses and a face of the revolving system; while another represented a section of the zone or fixed system, and the rays of light from the central lamp passed through this section, and were only diverted from their course with regard to their vertical dispersion. Those rays, in so far as they were separated from each other horizontally by radial dispersion, were not touched. Now the same thing might be done with reflectors. Fig. 10 represented the section of a reflector shaped according to the surface of a solid formed by the revolution of a parabola whose focus was at *a*, round the parameter *b c*. The property of such a reflector, as was well known, would be that all the rays from the central focus would be brought to a horizontal line with regard to vertical dispersion, but would be left untouched with regard to radial dispersion.

Fig. 10.



Now if this apparatus were metallic, made of good materials, and of the same dimensions as the dioptric zones; if the light were the same; and if it reflected the rays under the same conditions as the zones which transmitted the rays, would not the effects be the same? He thought they would, but with two exceptions. One was, a ray of light suffered greater loss by dissipation from the surface of the reflector than it did in passing through glass; and another was, that the apparatus in which the light was exhibited was in the way of the rays of light which passed through the centre, so that any pedestal, used to support the light, and the lamp itself would be in the way of all the rays which came from the reflector. That was undoubtedly a great drawback, especially in lights which could not be supplied horizontally; otherwise it might be practically equal to the dioptric system.

One advantage attending this arrangement, which did not appear at first sight, was, that a single instrument of this kind would illuminate the semi-circumference of the horizon, viz. 180°. It could not be made to illuminate more than that, and he was of opinion if it were made of the same size as the zone of M. Fresnel it would do it nearly as well.

Now with a Fresnel apparatus there could not be a second one, but with this there might be two, or more, side by side, and they would all illuminate the same 180° of the horizon; in which there was this advantage, that there would be practically no chance of the light being extinguished. If the chances were 100 to 1 against one light going out, the chance of two going out at the same time was 100 times 100 to 1, and against three being extinguished 100 times 100 times 100 to 1, that was, 1,000,000 to 1. One principle involved in this, and carried out in the other system, was capable of a valuable extension, but he did not see any account of it in the Paper, and he brought the matter forward now in the hope that if it had been carried out the Meeting might be informed of it. It was the principle of separating the vertical from the horizontal divergences.[1] In this and in the dioptric zone the vertical dispersions were taken by themselves; the horizontal dispersions were not touched. Mention was made in Mr. Stevenson's work of a contrivance of M. Fresnel, which he called the application of a cross prism. He had already explained that the system of zones condensed all the rays vertically only, so that if a lighthouse furnished with a system of zones, and a strong light in the middle, were situated in the middle of the sea, there would be a cylinder of light of a depth equal to the height of the zones, and a diameter that of the distance of the horizon on all sides. Supposing this zone were turned sideways, the same effect would be produced laterally as was before supposed to be produced vertically. All the horizontal rays proceeding radially would be collected in horizontal lines parallel with each other as regarded their horizontal relation to one another. The idea of Fresnel was to have a series of prisms, the present system of zones, to remain as now with the light in the centre, and another series of upright prisms outside, a wall of them being so arranged that these should have the effect of collecting the rays laterally, the inner zones collecting them vertically. In order to explain the effect of this combined system of crossed prisms, or zones, he would first notice the effect of the single dioptric series. Now the effect of these zones being to collect the vertical rays only, a spectator a mile off would see at every part, from the top to the bottom of the zones, rays coming from the lamp to his eye as a string of light, of the breadth of the flame; and hence according to the breadth of the flame in the centre, so broad a bar of light would he see from the top to the bottom of that zone. In respect to the joint action of these

[1] The term dispersion has been used to designate the natural separation of the rays of light from one another to fill the sphere of illumination, such as might be supposed to take place if the light were a single point. Divergence is here used to signify that abnormal deviation of the rays from the proper line of refraction or reflection caused by the angle subtended by the edges of the flame.—J. T. C.

zones with another system outside it, collecting the rays laterally as well as vertically,—just as the first horizontal set of zones collected all the rays vertically and produced a vertical bar of light, leaving their horizontal dispersion untouched, so the vertical set of prisms would collect the rays laterally, and produce a horizontal bar of light extending from side to side, the whole breadth of the system. The combination of the two would produce a square mass of light, whose area would be equal to the one bar multiplied by the other. Fresnel's first idea was to collect the rays, and thus give a flash, but he had never carried it further. Colonel Smith thought it might be done with the object of increasing the horizontal divergence, the great drawback to the lens system being the short duration of the flash.

In a series of eight lenses, if each face was the side of an octagon, and the whole system revolved in eight minutes, the flash produced by the lens would only last for $6\frac{2}{3}$ seconds, the darkness occupying the remaining $53\frac{1}{3}$ seconds. That was owing to the lens being so far from the central light, that the angle subtended by the edges of the light was a very small one—5° only. As the lens was brought nearer, a larger angle would be subtended, and the flash would last longer; and therefore it was quite possible, with the cross prisms, inside instead of outside the zones, to bring them to half the distance, and obtain double the length of flash. From a measurement he had made he thought there would be a flash of about 12° instead of only 5°. It would also bring about a little of the effect which was still wanting in the dioptric lights, that of the flash of light beginning gradually, increasing to the full intensity, and then gradually passing to nothing. He would be glad to hear whether anything had been done in this direction, and whether it was considered possible to carry it out practically in the way he had suggested.

Captain Arrow said he did not profess to be a judge upon the scientific portion of the question. His own duties, and the duties of those whom he represented, were, in the matter of optics, confined to calling upon scientific men to provide such instruments as were adapted to each particular case, and to see that those instruments were made use of to the greatest advantage when supplied. At the same time the Trinity House had to provide the best possible organization of the lighthouse system of the country, looking to its necessities in every bearing; but on the purely scientific portion of the question they had to look to those who possessed a skill which he personally laid no claim to. As representing the lighthouse authorities of this country, he considered the dioptric system was a great improvement and a great advance upon the catoptric system. There were many points, not only in its beautiful arrangement, and the way in which the light was economised, which were in favour of the dioptric system, but there was great economy in the system, and, moreover, it added very much to the safety with which the English coasts could be navigated. All would admit that one of the great disadvantages of the catoptric system, setting aside its comparative waste, was the impossibility of using it with the precision which attached to the dioptric system. There could be no better instance of this than was shown on the chart of the Straits of Gibraltar, in lighting which he and his colleagues had taken a considerable part. Thanks to the scientific and manufacturing skill of Mr. Chance, with which he had always been ready to assist the Trinity House; thanks also to Professor Faraday, great advances had been made in the lighthouse system; but in the Gibraltar light there was a peculiar illustration of the advantages of the dioptric system. The Pearl Rock was nearly 6 miles from the mole, and at that distance the red-coloured glass caused so much absorption, that it was difficult to get an effective red light except in the brightest weather. Fortunately, in the Mediterranean the sky was generally bright. The question before the Trinity House was how to utilise this light, so as to guard the Pearl Rock without the cost of a second light upon Cabrita Point, which would have involved a complication with the Spanish Government in addition to the expense. That gave rise to the employment of the beautiful arrangement of the vertical prisms, which by the skill of Mr. Chance had been so adjusted as not only to attain the object desired, a good red fixed light at a distance of 6 miles, but as he was told, on the best authority, the red rays were quite equal to the white at any distance the light was visible. By the accumulation of light from other portions of the arc, the obstruction from the absorption of the rays was so completely overcome, as to make the red light equal to the white.

Another case in point was afforded in the Dartmouth light, Plate 15, Fig. 10. He could say, as a sailor, that it would be impracticable to run up that channel with a bearing of one catoptric light only. There must have been leading lights; but, by the existing arrangement of the dioptric light, the path of safety was distinctly defined; by the shade of red light on the one side of the channel and of green on the other, the ship's course was clearly pointed out. The green light was in itself a bad colour, but it was the only one that could be adopted there. One light thus did the duty of two. The lamp was a little bigger, and a somewhat larger quantity of oil was burnt than in the ordinary Argand lamp; yet that was made to serve the purpose of two lights, and was sufficient to define with the greatest nicety both sides of the channel, and was of the greatest practical benefit. Not long ago he anchored in Dartmouth, after which the weather came on thick and misty, though not sufficiently so to obscure all light. Under that condition of the atmosphere, he got the vessel under way again, ran her out, and doing his duty as a lighthouse officer, he tried these lights on both sides of the channel, touching the edge of the red and green alternately to satisfy himself that they were acting properly, and he navigated his vessel in a thick night with the greatest accuracy. That was a practical demonstration of the economy which resulted from the use of the dioptric light.

Some observations had been made with respect to the catoptric system, which were worthy of consideration. An immense volume of light proceeded from the catoptric light when burnt upon one plane, and when it could be shown in one beam it was very good indeed; and, to the best judges, it was difficult to say whether the revolving light of the dioptric system surpassed it. He believed he was right in saying he did not think there was a revolving dioptric light which surpassed two or three of the catoptric lights existing on the English coast. In the Beachy Head light, for instance, there were thirty reflectors on three faces, and upon each face there were ten lights set in one plane, showing a magnificent beam of light, with a lengthened and protracted flash, which was very useful, particularly in thick weather, when the difficulty was to catch sight of any light. If the flash were prolonged, so much the better; he need not say to those experienced in these matters that to pick up a light at all required a great degree of practice. He had stood on deck watching for lights up channel, and had looked and looked till he fancied he saw them, but it was a sort of *ignis fatuus;* and for this reason, if the flash could be prolonged without weakening its power, it would be of great value, as giving so much more time for the eye to receive the rays. He held, as the representative of the lighthouse authorities, that the revolving lights on the catoptric principle were so good at this moment, that it would require much consideration to disturb them, particularly where so great an amount of light was given, as in the instance he had mentioned of Beachy Head. There was no doubt economy in the dioptric lamp, but not to the extent stated. The tendency of the evidence given before the Royal Commissioners was, however, to the effect that the catoptric system of lighting, as carried out in this country, was a very powerful source of light. The Trinity House authorities were acting at this moment upon that view of the matter; and, while they were changing the fixed lights as speedily as they could to the dioptric system, they had no intention at present of changing the larger revolving lights, because it was doubtful whether it was possible to improve them much at the present time; but the time might come when a different opinion would be entertained. The present was an age of progress, and no one could tell whether experiments that were successful to-day might not be eclipsed to-morrow.

It appeared to have been a source of reflection against the Trinity House and other Boards that they moved slowly; but when they did move it was generally in a safe groove. Here was a case in point. It was mentioned by Professor Airy, that the relative power of the two South Foreland lights—one being dioptric, and the other catoptric, was undistinguishable; and in his voyage across the Channel, he was puzzled to decide which was the better light of the two, and he naturally laid that to something in the dioptric light which deprived it of the superiority it ought to have had. This was actually the case. It was a particularly old-fashioned lantern, which detracted from its value, though it did not detract so much from the value of the catoptric light. If that lantern had been changed two or three years ago, the whole work would now have to be gone over again, because at the South Foreland it was the intention of the Trinity House to place immediately electric lights in both towers, which would require different lanterns from those commonly used, and different arrangements, compelling a change altogether. Therefore, if this change had been made at an earlier period, it would have entailed to a certain extent a loss of money. He mentioned this circumstance to show, that the authorities could not move so rapidly as some people appeared to think they ought to do. As a public department, the lighthouse authorities did expect criticism upon the way in which they carried out their duties, and they were perfectly ready to meet anything in the shape of fair criticism; but he thought there ought to be some allowance made, and some credit given for the difficulties which the Trinity House had to struggle with, in having had to work a system of comparative antiquity. It was for a long period of time far in advance of that under the control of any other lighthouse authority, whether in Scotland, Ireland, or France; and therefore, being so far in advance, it was the more difficult to alter. On the other hand, the French jumped at once from the most insignificant lighthouse arrangements to a degree almost of perfection. They had no shipowners to consult; these matters were done in France with a stroke of the pen: an alteration was ordered, and it was made forthwith. But in this country nothing of the sort could be done. Those for whom these duties were administered did not find means for making unlimited experiments, nor would they consent to throw away a good thing for the sake of a better, unless it was proved that the old one was not good enough. From some of the remarks that had been made, he thought a little undue stress had been laid as to the improvement that was wanted in the organization of the Trinity House. He could understand that, to a person highly versed in optical science, in his view optical science was the great thing wanted. Perhaps the next criticism would be directed to something in connection with the construction of the lighthouses, or buoys, or lightships, all of these calling into play other branches of science. But it would not do to confine the organization to one of an optical, or of any special character only. The lighthouse authorities of this country had striven to make available every branch of science, so as to be able, in carrying out the details, to make use of all the appliances which science had placed at their command. Great thanks were due to the Royal Commissioners who sat some eight or nine years ago. They had, with much perseverance and pains, and he had no doubt at a large expenditure of money, accumulated an immense number of facts. He did not agree with all the conclusions they had arrived at; but he approved of a great deal they had done. To Professor Airy was due, he believed, the discovery of a means of effecting a more perfect adjustment of the optical apparatus, which the Royal Commissioners had adopted, the knowledge of which was previously unknown to the Trinity House, as he believed it was unknown to all other lighthouse authorities. The same defects existed in the lights in Scotland as in the lights of the Trinity House; and in the strictures which the Royal Commissioners had made the very worst light that was shown as being improperly arranged was a Scotch light. He believed the Royal Commissioners were under the impression at the time that it was an English, and not a Scotch light, but it was the worst on which they put their finger; so that the Trinity House did not stand alone in this, if it was a blot in the system. Thanks to Professor Airy,—thanks to the use made by the Royal Commissioners of his observations, he was glad to say the inquiry had resulted in public good. It only wanted to have the knowledge of the defect brought to light to induce Professor Faraday to set to work to rectify it; and when he said they had the advice of Professor Faraday, it would be admitted that they had appealed to a high and competent authority. Professor Faraday invented a small instrument which rendered it easy, with the most ordinary skill, to adjust any of the existing dioptric lights. Since then much attention had been paid to the subject, and, with the advantages of Messrs. Chance Brothers' manufactory, and Mr. Jas. Chance's mathematical skill, in conjunction with Professor Tyndall, whose scientific attainments had been of great use, he did not think it probable there would be any just cause of complaint, so far as the organization of the Trinity Board went, in respect to the question of optical skill. The lighthouse officers of the kingdom did their best; they never turned a deaf ear to any suggestion where they saw an opportunity of advancing in the right direction. The Royal Commissioners were armed with great powers, and had the means of arriving at facts which without those powers it would have been impossible to obtain; and they certainly had called attention to defects common to all lighthouse authorities. Since then great improvements had been made in optical apparatus. The vertical prisms were no doubt a step in the right direction; but there still remained much to be done, and he hoped to see improvements introduced which would diminish the cost of the dioptric lights, and make a smaller lamp do even greater work than the large ones did at the present moment.

Mr. R. P. Brereton remarked that he had had experience of Mr. Chance's great skill in the manufacture of optical apparatus for lighthouses, in the case of one constructed by him at Kingsweare, for the Commissioners of Dartmouth Harbour, the object of which was to give a sea-light, as well as to define distinctly by different colours the fairway channel to the harbour between the 4-fathom lines at low water on either side. The harbour entrance between those lines was narrow, and, as a white or leading light of only $9\frac{1}{2}°$ was required, it was necessary, to correct divergence of the rays over so small an arc, to have perfect appliances and very careful adjustment; and, from his own knowledge of the navigation, he could state that the objects in view had been remarkably well accomplished. The light, Plate 15, Fig. 10, was in itself simply a fourth-order dioptric light, with the refracting belts and reflecting prisms of the ordinary kind, and the whole of the light was directed seaward. From the land-locked nature of the harbour and the high ground adjoining, the direct light visible from the sea embraced only 45°, of which $9\frac{1}{2}°$ were white light, the sides being green and red. To intensify the rays of separation, or of transition between the bright and coloured lights, Mr. Chance had introduced vertical prisms of total reflection, five on one side and five on the other: four of these prisms condensed the light upon the edge of the red and four upon the green. The two outside prisms were for the increase of the direct bright light to sea. These vertical prisms were placed outside the illuminating apparatus, and the coloured shade shown by the green and the other by the red. Captain Arrow had remarked that green was a bad colour, but Mr. Brereton found, in coming up the channel, that though the green light was not so distinctly seen as the red and white lights, still the object was attained by navigators, who, when they ceased to see the bright light and did not catch the green, knew they may be getting into dangers, the whole of which, however, lay within about a mile and a half off shore, where the colours were distinctly seen. Although this was only a fourth-order light, it had been seen in clear weather at a distance of 18 to 20 miles, which was nearly equal to a first-order light.

Dr. Gladstone remarked, that though he had listened to Mr. Chance's elaborate Paper critically, there was nothing in it which he could find fault with; therefore the few observations he should make would only be supplementary.

First of all, he would say a few words on the question of catoptric and dioptric arrangements. Mr. Chance had stated that the dioptric was superior to the catoptric, and he had laid it down, that the best way of judging of the comparative merits of the two systems was to go to the French comparisons. Though Mr. Chance did not give these comparisons, still they were stated to be in favour of the dioptric arrangement. He had no doubt it was so. But it was scarcely fair to the English lighthouse keepers to compare them with the French, for this reason, that he never knew a French keeper who could polish a silvered mirror well; and the polishing of the mirrors was a most essential matter in the catoptric arrangements.

The question had been ably discussed on many points, but it seemed to him to admit of some further consideration. It had been said that the Fresnel lamp could not be multiplied, that the four-wick lamp was as large as it could be, and that but little improvement could be made in the optical arrangements; but the Argand burners and mirrors might be multiplied *ad infinitum*, and thus a brighter light might be produced by the catoptric than by the dioptric arrangement: and this might explain some of those curious anomalies which at first seemed unintelligible. Thus there were Professor Airy's observations, that the two lights of the South Foreland appeared to be very much alike, which, indeed, they were: then there was the fact alluded to by Captain Arrow, that on an examination of the lights by the Royal Commissioners, they came to the conclusion that many of the catoptric revolving lights, including that at Beachy Head, were the most beautiful exhibited. The reason was, the mirrors could be multiplied, and there might be thirty Argand burners, ten at once sending rays all streaming across the surface of the ocean in the direction wished; and if ten were not sufficient, there might be twenty or thirty burners, all sending their rays in the same direction: but it could of course only be done at a largely increased cost; and the Beachy Head light consumed 1,000 gallons of oil annually. Another advantage of the catoptric system was that it helped to afford the required distinction between different lights on a sea-coast. Mr. Chance had shown the great distinction between fixed and revolving lights. Dr. Gladstone had not much love for fixed lights, inasmuch as they were easily confounded with lights on shore or on board ship; and whereas a fixed light was always the same, many different kinds of lights might be made to revolve at various rates of speed, and to display various alternations of colour, as in some of the most beautiful lights in France and Great Britain. Then, again, there might be short flashes and prolonged flashes. With an electromagnetic apparatus the line of light was a sharp line which rapidly passed away, and at a distance there was scarcely any light excepting at intervals, when there was a sharp flash, rapidly disappearing ; whereas with the large mirrors at Beachy Head, there was always a strong light ; but this light once in every two minutes gradually increased to its maximum of brightness, and then diminished again. In this respect there was an appreciable difference between a revolving catoptric and a revolving dioptric light. The general result he arrived at was, that without doubt on scientific, practical, and economic grounds, the dioptric light was, on the whole, the best ; but there were advantages connected with the reflectors which must not be lost sight of, and he thought the authorities acted wisely in retaining those beautiful lights, which had been alluded to, on the British coast. Now that the better adjustment of the glass apparatus was introduced, he had no doubt the dioptric system would show its great superiority. On the subject of adjustment, he would say that the Royal Commissioners learnt from the evidence of many witnesses, that the light at Cap Grisnez was a very beautiful light. When the Commissioners went to France and saw the lighthouse authorities there, they expressed a wish to visit and inspect that lighthouse ; but they were told that, inasmuch as it was an old-fashioned light, and one of the first that had been made on the lens system, they need not trouble themselves about it. They went as advised to Cap D'Ailly and Calais, where there were very beautiful modern lights, but they also did trouble themselves about Cap Grisnez. And here he must go a little into the history of the thing, as it had not been quite correctly represented. The secretary of the Commission, Mr. Campbell, being a photographer, thought of this principle of internal observation for the purposes of adjustment of the apparatus. When he mentioned it to the Commissioners, they at once saw the value of the suggestion, and it was applied in various ways ; and this method of observation was employed at the Start light, and subsequently at Cap Grisnez. It was found with astonishment that the latter was beautifully adjusted, and there were reasons for believing that M. Fresnel had adjusted it somewhat upon the principle now adopted. That solved the secret of the beauty of the light at Cap Grisnez : while the upper and lower mirrors were only quicksilvered ones of a very poor description, the whole was so well adjusted as to send a beam of light right over the English Channel. This tended to give the Commissioners additional confidence in the importance of correct adjustment, and they pointed it out at the North Foreland to the Elder Brethren of the Trinity House, to Professor Faraday, and other lighthouse authorities. It was after his visit to the Start, in conjunction with the Royal Commissioners, that Professor Airy visited the Whitby lights, where, as he said, he first woke up to the importance of the method of internal observation. Thus it was not he who first brought this plan before the notice of the Royal Commissioners; on the contrary, it took some time to convince him of the importance of the matter. It was, however, now appreciated by all parties, and to Professor Faraday they were indebted for some of the practical arrangements for carrying it out.

He would add that all these beautiful arrangements required not only good adjustment, but that all the parts should work together to make the light as perfect as possible. In inspecting one of the lights devised by Mr. Stevenson, in one of the narrow channels on the west of Scotland, it was found that there was an astragal in the way of the most important beam of light. In passing in front of the harbour light of a principal seaport, the light was found suddenly to disappear, and then appear again. On visiting that light it was found that in front of the apparatus, which was a very good one, there was a pillar 4 inches or 5 inches broad just in the most important part, and the inspecting party had been going through the dark shadow cast by this pillar. The practical observations of Mr. Chance with regard to divided responsibility in these matters should be borne in mind In operations like this all should work together, and there should be perfect harmony of action between those who planned the lights and those who constructed or erected them.

Admiral Hamilton, chairman of the Royal Commission on Lights, Buoys, and Beacons, said the Commissioners found on examination, that the Trinity House had endless difficulties to contend with; and under such circumstances it was evident the system could never work properly. If the Trinity House made suggestions, these had to be laid before the Board of Trade, who looked too exclusively at the economical side of the question, and too frequently said "No," without the intervention of any scientific person, and the Trinity House were hampered in every way. Looking over the report of the Royal Commissioners, for the first time for many years, he adhered to everything it contained. He believed the Trinity Board had taken that view which Captain Arrow gently touched upon, that the Commissioners had been hard upon them, and had not done them justice in their report; but he was glad of this opportunity to refer to a paragraph of the report which he thought entirely took away the sting which Captain Arrow had hinted at; and if he got the support of the Royal Society on one point recommended in that report—if the Trinity House would take it as it was meant, and not view it as reflecting on their administration—it would be for the advantage of science, he thought, that that recommendation should be carried out. Captain Arrow, in his remarks, assumed that optical science was paramount with the Commissioners. In some sense that might be true; but so far from ignoring the other branches in connection with this subject, he was sure that if Captain Arrow would but turn to that section of the report under the head of "Quality of lights," extending from page vi. to xii., he would admit that a vast deal more was touched upon than the mere optical question, and that the immediate practical points connected with the objects of lighthouse illumination were borne in mind.

He would also call attention to the 19th paragraph of his own letter, in which he said :—"And in order to satisfy the public that our Lighthouses, and the whole system of Lighthouse illumination, are in all respects what the highest state of science can produce, and the interests of this great maritime country require, the Queen might be advised to issue her warrant appointing the President and Council with other Fellows of the Royal Society annually to visit the central establishment at the Trinity House, as is now the case with the Royal Observatory ; and that the Trinity Commissioners for Lights should on that occasion submit a report of their proceedings in all matters relating to the development of and improvement in Lighthouse illumination to the Visiting Board of the Royal Society ; such report to be presented to Parliament with the annual estimates."

The Commissioners advised that the Trinity House should have placed at their disposal and service the assistance of men of science, and that the constructive details should also be carried out under their direction and superintendence. He could not say how much the Royal Commissioners were indebted to Mr. Chance. The Trinity House, and others who were interested in the maritime concerns of the country, were aware how much was owing to him, and Admiral Hamilton considered himself fortunate in having been at the head of an inquiry in which the services of such a man as Mr. Chance could be made available. Allusion was made in the report to the superiority of the building of the lighthouses. There were none superior to those built by the late Mr. James Walker (Past President Inst. C.E.), and he greatly regretted that the name of that eminent man in connection with them had been omitted. In conclusion, he would say that the primary object on the part of the Royal Commission had been to assist the Corporation of the Trinity House as much as possible.

Captain Arrow assured Admiral Hamilton that his allusion to the Royal Commissioners had not been made in any unkind spirit; but he thought the remarks of Professor Airy were of a character rather disparaging to the lighthouse authorities and their officers, and it was to those remarks he had alluded. He never meant to cast the slightest reflection upon the Royal Commissioners.

Mr. Babbage observed, that he had but little to say on this subject, except to express, in common, he believed, with all who heard it, how highly he appreciated the excellent Paper, and the equally admirable tone in which the Author's explanation of it was expressed.

Of course it was impossible that all the details could be read at one meeting; and consequently questions were asked on subjects, which he had no doubt would have been answered by the Paper itself. He had himself no criticisms to offer on the subject; but he thought this beautiful apparatus was capable of being rendered of still greater utility. Most lighthouses were upon the revolving principle, some revolving with more, and some with less velocity; and others had temporary eclipses; but there were circumstances which were greatly influenced by the state of the weather, in certain conditions of which there was difficulty in estimating even roughly the distance of a lighthouse from a ship. There was another way in which these lights might be utilized, still, however, preserving them for their primary purpose of lighthouses: he alluded to the adoption of a system of signals, which in some cases might be of the greatest use; and he believed that it could be accomplished without any diminution of the intensity of the lights, or for the primary purposes for which they were required. By this plan, which occurred to him fifteen years ago, he produced occultations, and the system of signals he proposed would be governed by the number of occultations, and by the amount of light intercepted by each. Seeing this beautiful instrument, it occurred to him that it might well be employed for that purpose. During the Exhibition of 1851, he had an occulting light placed on the roof of his own house, with a view to experiments upon its adaptability for telegraphic communication; and subsequently he received a communication from America, requesting him to visit that country to establish that system there.

He thought he might be permitted to state a curious fact relating to the effect of these very rapid occultations upon the mind. He had produced occultations so quickly succeeding each other, that he was aware of their being double occultations before he was enabled mentally to put into mental language the expression of that fact. This system of rapid occultations appeared to him capable of adoption for signalling purposes; and he thought that in the hands of the manufacturers of these instruments, it might be turned to some practical account. He had published an account of this system fifteen years ago; and yet, such was the state of the Government of this country with respect to scientific matters, he understood the Government had adopted the principle without the slightest acknowledgment of it in any way whatever. As an Englishman, he would say he thought it was an unworthy thing for persons at the head of affairs to do that in their official capacity which would justly be esteemed disgraceful if it were done for personal ends.

Mr. JAS. N. DOUGLASS said, the first order apparatus of the Gibraltar lighthouse for a fixed light with vertical condensing prisms, to which Mr. Chance had referred in the Paper, was an instance of care in design, great perfection in the material of the glass portions, and optical accuracy in construction. To show with what precision this apparatus was erected by Messrs. Chance he might state, that considerable improvements were made by the Corporation of the Trinity House, at this lighthouse, in 1863-4, and it was determined in designing the new dioptric apparatus, which was to illuminate 288°, to have in it an arc of 23° of very powerful red light, for the purpose of marking the Pearl Rock Shoals off Cabrita Point, at a distance of five miles from the lighthouse. The work was so accurately performed, that when the light was tested by a Committee of Elder Brethren of the Trinity House, the line of demarcation between the white and the red lights at the Pearl Rocks was found to be identical with that determined on, and not the slightest alteration was required in the adjustment of the apparatus.

He had had many opportunities of observing from the sea the relative illuminating power of the two lights at the South Foreland; and he had noticed, like the Astronomer-Royal, that on some bearings at sea the upper, or dioptric, appeared, as it should do, the more powerful, and on other bearings the lower, or catoptric, seemed to have the advantage. He would briefly describe the illuminating apparatus in each lighthouse, and the reason, in his opinion, for the observed difference in illuminating power on certain bearings. The low lighthouse had fifteen paraboloidal silvered reflectors, 21 inches in diameter, and Argand lamps with $\frac{7}{8}$-inch burners. The apparatus illuminated a sector of sea surface of 199°, giving 13° 16′ as the work of each reflector; therefore, as the reflectors had each a divergence of 15°, the light should be practically uniform in illuminating power throughout the above sector. The high lighthouse had a first order dioptric apparatus for fixed light, manufactured by Lepante, of Paris, in 1841. It was composed of six 45° panels of refractors, two 45° metallic spherical reflectors, and nineteen zones of prisms, thirteen upper and six lower. The apparatus illuminated a sector of sea surface of 270°. The apparatus and lantern, like all those of French manufacture, were constructed with vertical and horizontal framing, the vertical portions opposing at every $22\frac{1}{2}$° an obstruction of the light equal to about 40 per cent. This obstruction was so much increased, when the compressed intense illumination of the electric light was used, during the experiments that were made by the Trinity House with this light in 1857-8, that the officers of steam-packets crossing the Channel were known to have used the partially illuminated bearings for checking their position at sea.

As was stated in the Paper, the illuminating power of a fixed dioptric light was about only $\frac{1}{8}$th that of the best revolving dioptric light of the same order; it was, therefore, of the utmost importance in a fixed light, that the whole power of the apparatus should be sent to the mariner practically unimpaired by obstruction of framing throughout the whole illuminated sector of sea surface.

To the late Mr. Alan Stevenson was due the introduction of inclined framing for the apparatus and lantern, for the purpose of reducing the obstruction of light, and distributing the reduced obstruction nearly equally over the illuminated sector of sea surface. Inclined framing was also adopted by the late Mr. James Walker; in both instances the lanterns were framed with gun-metal, and glazed with flat plate-glass. In designing lanterns for the Trinity House, he had lately, with the view of reducing the obstruction of the light to a minimum, as well as that of the aberration of the rays proceeding from the single lamp of a dioptric apparatus, adopted the cylindrical form for the lantern, with steel for the framing, the latter having an inclination of 30°, and helically curved throughout. A first order lantern of this description was shown in elevation and section in Plate 16, and a small model of the glazed portion and its framing was also exhibited. Before constructing one of these lanterns, he had made some experiments with various forms of framing, in which he had the valuable advice and assistance of Professor Faraday, the scientific adviser of the Trinity House; a section of the framing, full size, was placed before a first order dioptric apparatus and lamp for fixed light, and it was found that no visible shadow was cast upon a white screen placed only 45 feet from the light. Professor Faraday reported on the experiment as follows, "A full-sized model of part of a lantern on the construction of Mr. Douglass was placed before the lamp and optic apparatus. It cast no sensible form of shadow on the screen. In fact, the whole amount of shadow was a minimum, and it was uniformly (or nearly so) diffused over the illuminated interval. I conclude that it would be nearly a matter of indifference (as regards shadow) where the uprights of the optical apparatus were placed in relation to such a lantern."

The framing of the lantern was of puddled steel, having a tensile strength of 32 tons to the square inch; it was rolled in halves, as shown in sectional plan at E F, Plate 16. The quadrilateral and triangular frames were welded together at the top and bottom corners, and were adjusted to size and curvature on a guage block: they were afterwards fitted and riveted together, each pair of quadrilateral frames fishing the junctions of the frames above and below them, and thus forming a rigid framing, of nearly uniform sectional area and strength throughout the lantern, for the support of the plate-glass. The framing was riveted together at the workshop into eight triangular sections the whole height of the lantern, leaving only eight joints to be riveted up at the lighthouse. The rebates of the frames were all carefully adjusted to standard templates, to which the plate-glass was manufactured by Messrs. Chance, so that the panes of glass might fit throughout any lantern of the order to which they belonged. The fillet in the sash-bar to receive the glass was parallel with the front of the sash-bar. The glass was not flat, forming a structure in facets as in lanterns previously constructed; but it had the necessary curvature given to it, so as to form, when glazed in the lantern, a true cylinder, affording the greatest degree of optical accuracy for the transmission of light from the central illuminating apparatus. The glass was secured in position by gun-metal cappings screwed to the framing. A supply of spare panes was kept at each lighthouse, so that in case of accident to a pane, it might be immediately replaced by the light-keepers. Several of these lanterns had been erected, and one was exhibited by the Corporation of the Trinity House at the Paris Exhibition, with a first order dioptric apparatus in position, manufactured by Messrs. Chance.

A cylindrical lantern specially designed by Messrs. Chance for their dioptric apparatus, in which the English electric light was exhibited at the Paris Exhibition, might also be seen on a lofty temporary scaffolding in the Park. This lantern had horizontal, vertical, and inclined framing, nearly all of which was made to coincide optically with the framing of the dioptric apparatus for fixed light.

He might extend his remarks on the first order cylindrical lantern, to the special arrangements for ventilation, to meet Professor Faraday's views, for distributing the upward current over the internal surface of the lantern glass, and thereby preventing condensation thereon; but, as he was about to prepare a Paper for the Institution on the construction of lighthouses, he would in doing so go more fully into that subject.

Mr. C. W. Siemens said, it had been objected that the Paper was not of an engineering character, but the subject was intimately connected with engineering, and had been received with interest by the members. Mr. Chance had confined himself to the optics of lighthouses, which was a large subject by itself, although many would have liked to have heard about their mechanical construction, on which he had so much practical experience, and also on the constitution of the glass, which Mr. Siemens believed was of great importance to the results obtained. The description of glass used in the lenses and prisms was, he understood, generally flint-glass—that was glass which had oxide of lead for its base; but this glass varied very much in quality. A small addition of lead would increase its refractibility considerably, and he knew there was difficulty in getting an even mixture at the top and bottom of the glass pot. He therefore thought there must be some special means of obtaining uniform refractibility, or some ready means of adjustment for differences in the degree of refractibility, which he would ask Mr. Chance kindly to explain. One point of great interest had been touched upon, which should be fully discussed. The Astronomer-Royal, in going from Dover to Calais, observed that at a certain distance from the two Foreland lights, one dioptric and the other catoptric, the two showed no essential difference in intensity, though the dioptric light was far more brilliant than the other when viewed from a short distance. No explanation of this observation had been offered, and he would merely suggest whether it might not be the case that, although the dioptric light was the more brilliant in itself, it would nevertheless, at a considerable distance, produce the same effect only as the other light for the following reason: If light might be regarded as a vibratory motion of the medium through which it was transmitted, any obstructive matter in the form of haze or smoke must exercise a destructive effect according to the square of the energy of vibration, or intensity of the light. If that were the case, it followed that a brilliant light would in an obstructive medium soon subside into a light of moderate intensity, and thence proceed at a more equal rate of diminution with light proceeding from a less brilliant source but of equal magnitude, the latter being chiefly determined by the extent of light-emitting surface. For instance, one light produced by a candle would be lost sight of, under certain atmospheric conditions, say at a distance of half a mile. But with six lights of the same size placed side by side, a sufficient amount of light would be conveyed to that distance to produce a distinct effect on the eye. In the same way the glare of the gas-lights of London was seen at a distance of twenty or thirty miles, whereas a limited number of more intense lights would be lost to sight at that distance. He therefore thought the quantity of light emitted was of more importance than its intensity in seeking distant effects, a circumstance which had not perhaps been fully considered in estimating the relative value of the electric light, as contrasted with the ordinary optical apparatus of extended surface.

The question had been put, whether the dioptric light was, under all circumstances, better than the catoptric; and the Author of the Paper seemed to be much in favour of the dioptric system. Now it appeared to him that, for lights of comparatively short range, the catoptric system could be used with advantage, because the reflecting mirror was the more simple arrangement; and if its surface could be kept clean, it would reflect the light in a certain definite direction without much loss, provided the parabolic mirror were extended far enough over the light. The principal drawback appeared to be, that the surface of the parabolic mirror became tarnished; and in order to prevent that, he would recommend those interested to try pure nickel surfaces, produced by the galvano-plastic process. He had tried them, and he thought they were perhaps of all metallic surfaces the least apt to tarnish. Nickel was as hard as hardened steel, and it seemed to remain perfectly bright under all atmospheric influences, even in rooms where sulphuretted hydrogen was present.

There was one other light, which had occupied his attention during the last twelvemonths, to which he would refer:—Mr. Thomas Stevenson, of the Northern Lights, had proposed to establish flashing lights (that was to say, lights giving out flashes at certain intervals) upon beacons and buoys; and Mr. Siemens had been applied to with a view to accomplish that object. The source of light was to be upon the land, because there were periods of the year when a landing could not be effected with safety at the beacons or buoys; and the source of light which naturally suggested itself under these circumstances was electricity. The apparatus that had occurred to Mr. Stevenson was the Ruhmkorff coil placed upon the land, and communicating with the beacon through a cable: but the preliminary experiments at once showed, that the discharge of a Ruhmkorff coil would be absorbed in a cable of only 100 yards in length, and that no spark would be produced on the beacon. The next thing tried was to place the coil on the beacon, and to send simply the battery current through the cable: a cable having a large metallic section was taken, but nevertheless the absorption was such, that no perceptible spark could be produced. Under these circumstances the idea suggested itself to him, that a simple metallic circuit might be established through the coils of an electro-magnet, and that the extra current produced in breaking that circuit would produce a flash, close to the electro-magnet upon the beacon, which would be increased rather than otherwise by the accumulated charge in the connecting cable. If this could be practically accomplished, then the light might be placed at a considerable distance from the shore, without destroying the battery effect which had to be transmitted from the land through a cable. The apparatus was not perfected at once; but he had placed one on the table which would accomplish the object in view. It comprised a heavy electro-magnet, the coils of which were supposed to be in communication with a battery on land through a cable. A clock-work apparatus on land established the electric circuit through the cable at certain predetermined intervals. The electric circuit through the cable was, however, not complete, unless the weighted armature of the electro-magnet was in its distant or unattracted position. The attraction taking place, the circuit was broken at the point of a platinum pin, which was drawn from a mercury bath, and a brilliant discharge of extra current ensued. The current being thus broken, the armature fell back and re-established the circuit, when it was again attracted, and a discharge again took place, and so on during the periods of time when the circuit was established on land. The mercury was continually renewed at the point of contact by means of a circulating pump, which was worked by the electro-magnet itself, which latter had to be very powerful in order to produce an intense light in its discharge. The point of discharge was placed in the focus of a dioptric or catoptric reflector, upon the beacon or buoy to be lighted. This apparatus had only lately been completed, and had not yet been tried at sea; but it had been at work experimentally for some time, and appeared to give very constant effects. If this apparatus was constructed for throwing the light only through a limited arc, the effect would be much intensified; and in that form he thought it might be placed with advantage at narrow entrances, where each light would tell its tale by the periods of successive flashes peculiar to itself; and since the succession of flashes could be varied at will by the contact arrangement on land, the apparatus might also be used for conveying special warnings or signals to vessels out at sea. This apparatus was only applicable to a succession of flashing lights.

Mr. Campbell, Secretary to the Royal Commission on Lights, Buoys, and Beacons, said his knowledge of the subject was chiefly gathered during the time that the Royal Commissioners were at work, between 1858 and 1861; he had not considered much about it since the report was presented, but he understood that there had subsequently been great improvements. He thought, however, he could explain why it was that the dioptric was not better than the catoptric light at the South Foreland, at the time when those two lights were observed and compared by the Astronomer-Royal. The dioptric apparatus was not then adjusted so as to make the best of the light produced by the lamp, and the flame of the lamp was inferior to flames observed elsewhere. The apparatus was constructed to throw light horizontally, but at the South Foreland it was placed as high as 372 feet above the sea. The flame itself was small and low, and consequently observers on board ships crossing the channel saw chiefly the points of the flame through the glass of the apparatus. The flame was inferior to begin with, and the best of the light produced by it was thrown on the sky far above the visible sea horizon, distant 20 miles. On looking through the glass apparatus from within, the sea horizon was not seen by Mr. Campbell from the proper places through different parts of the apparatus.[1]

[1] For an account of observations made by the Commission which bear upon this point, see Report, vol. i., p. 49, pp. 52, 53, where illustrations are given of the

Now, if the apparatus had been properly adjusted, he believed that this light would have compared favourably with the other light; but he could not speak to the fact from his own knowledge, for he had not, since June 20th, 1860, compared the two lights from the sea.

Admiral Ryder, a member of the Royal Commission on Lights, Buoys, and Beacons, said he had no doubt but that great pains had been taken to prepare the beautiful dioptric lights of Mr. Chance, for England, Ireland, and Scotland. In Great Britain, where intelligent observation was applied to them, they did their duty well; but in the colonies, a different state of things obtained. The same kind of instruments were sent out; but when they arrived, from ignorance on the part of the people who had to do with them, they were mismanaged to a great extent. He would mention the state in which he had found a first-class, revolving, dioptric light, at Bermuda. The island was surrounded by rocks to a great distance on one side, and it was most important that this light should do its duty thoroughly. On approaching the island, he saw the light at a considerable distance. The ship was anchored in the basin—a distance of about 4 miles from the light—on the next night after his arrival, and he was anxious to watch the light previous to the visit he proposed to make to it. To his great surprise, after it was lighted, no flash was visible from the deck of his vessel, the 'Hero,' a line-of-battle ship. His eye was about 34 feet above the water. He thought at first that the keepers were dilatory: in a little time he saw a faint light; but after watching hour after hour, there was no appearance of the flash. He then sent a midshipman up the rigging, telling him to report to him as soon as he got into the flash; but it was not till he had ascended a height of 80 feet from the deck that he did so. Below that height there was only the dim light which came through the lower prisms. Most fortunately the flash reached the horizon; but for many miles from the base of the lighthouse there was no flash to be seen, except at a considerable height above the sea. He afterwards visited the lighthouse, and ascer-

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adjustment of flames and apparatus at Grisnez and at South Foreland. See also "Explanation of the Drawings," p. 226, and the drawings in vol. i. For the general subject, see the Report and Appendices. The Commission proved that "the dioptric apparatus in the United Kingdom was not always arranged so as to be turned to the best advantage: that the amount of light produced was often deficient: that the optical apparatus was often so adjusted as to waste a great part of the light produced." But since 1861 it is understood that many of these defects have been remedied, by the use of improved lamps, and by the readjustment of the optical apparatus. The South Foreland dioptric light was visited and hurriedly re-examined by Mr. Campbell, Sept. 15, 1866, and the sea horizon was then seen in the proper direction through all parts of the apparatus, which were tested by looking through the glass. Mr. Campbell said his information was out of date, because it relates to a state of things which appears no longer to exist, at least at the South Foreland.—J. F. C.

tained the cause, with which he had already become familiar in previous inspections of other lighthouses. He found that the instructions given to the keeper were to keep the lighthouse thoroughly clean and to burn as little oil as possible. The keeper was a very intelligent man, and Admiral Ryder learnt a good deal from him as to the smaller details of lighthouse management in the tropics; but the keeper evidently prided himself on his economy of oil. There was a paltry little flame, of not more than an inch and a half in height, and the best part of the flame was at a considerable distance below the foci of the lenses. This was the reason that there was no flash visible from the deck of any vessel, except at a considerable distance. A vessel in thick weather going within that range would be in danger of getting on the rocks. He mentioned this circumstance to the Lighthouse Commissioners, consisting of the naval Commander-in-Chief, Sir A. Milne, the Superintendent of the Dockyard, and others, for it appeared to have escaped their notice. The lamp was not a pressure lamp, but the ordinary lamp used by the Trinity House in England previous to the issue of the report of the Royal Commission. There was no means of rectifying the evil except by raising the lamp, and directing the keeper to burn as much oil as possible. This was the only thing that could be done, as the purchase of a pressure lamp was objected to. The lamp was accordingly raised $\frac{3}{8}$ths of an inch, and the next night after that was done a splendid flash could be seen from the decks of all the vessels in the basin at 4 miles' distance. Thus this light, which no doubt cost between 3,000*l.* and 4,000*l.*, had been worked, up to the period of his visit, in a manner which made it almost useless as a danger-signal at the time when it was most required. He subsequently went to Halifax, another most important port, to which large-class steamers were running daily. At the entrance to the harbour there was a dangerous rock, on which a lighthouse was placed. He made a point of visiting all the lighthouses he could, and accordingly went to this lighthouse, in company with the Commander-in-Chief of the station, Sir A Milne, and there he found the following to be the condition of this most important lighthouse. He found a dirty table, on which were placed nine very poor Argand lamps. There was no arrangement whatever for securing that the rays should be directed in any particular direction, and the lamps were so placed as to leave dead angles. The reflectors were more than fifty years old, and as dull as pewter. He noticed that a small chip of wood was placed underneath the front of each lamp. He asked what the object was in using those pieces of wood, and the reply of the keeper was, that they were used by his father before him, to prevent the oil from flowing over too much; those chips of wood had probably been in use for the last forty years for the same purpose. He measured the angle of error introduced by those pieces of wood, and found that it was from 3 to 5 degrees; so that all the brightest rays had for years been thrown to the stars. He wrote to the Governor of the Province and to the Board of Trade on the subject, and suggested that there ought to be at least a second-class dioptric light at that spot; but he believed the result was nine new Argands or nine new reflectors were substituted, and the pieces of wood, he had no doubt, were still used in the same manner as they always had been. If that was the state of two most important lighthouses in English colonies at no great distance from England, and which were constantly visited by men-of-war and merchant-ships, what was likely to be the state of those situated at great distances on the other side of the world? There was but one remedy, viz., that one or more inspectors of lighthouses should, after being thoroughly instructed in every branch of lighthouse management and adjustment, visit periodically all colonial lighthouses, say triennially, and report in detail to the colonial authorities and the Board of Trade.

Mr. Chance, in reply upon the discussion, said regret had been expressed that certain subjects had not been treated in the Paper. In the few observations he had made after the reading of the Paper, he explained that its limits precluded him from touching upon particular subjects in a manner to do justice to them. He confessed that it had not occurred to him to refer to the constitution of the glass, to which Mr. Siemens had alluded; not because there was any secret connected with it, but because it was a chemical subject; and also because any kind of colourless, transparent glass might be taken to produce the effects required in lighthouse apparatus. The glass used by him was of the ordinary kind—not that called flint glass, which had the higher refracting power. The glass ordinarily used was of low refracting power; its index being under 1·52. Professor Airy regretted that the mechanical portion of the subject had not been more fully treated. That constituted by itself a large division, and could not be introduced into the Paper; but the particular point to which the Astronomer-Royal alluded had been purposely omitted. The Astronomer-Royal referred to the Start Lighthouse, concerning which he expressed the suspicion, after having examined the optical apparatus, that the convex surfaces of the lenses were spherical round one common centre, instead of being annular (except at the central disc), generated round a common horizontal axis, but not having their respective centres of curvature in that axis. He had reason to believe from communications which he had received that such was the case; but considering that this apparatus was constructed about 1836, and looking to the correctness of shape to which the annular lens had been brought by Augustin Fresnel as early as 1822, it was not for him to record how, after so long an interval, such backwardness of execution was still existing in this country. He would, however, suggest, by way of explanation with regard to this matter, that this was nearly the first—if not the first—attempt, in this country to produce the Fresnel lens. It was made at the works of Messrs. Cookson, at Newcastle-upon-Tyne, and what this firm then accomplished was exceedingly creditable to them. His object, however, had been not to record failures, but rather the successive steps of progress, whether in this country or abroad. He was very glad indeed to have had the help of Mr. Campbell and of Admiral Ryder in the explanation of what must have struck all who heard it as a discrepancy between theory and practice. The theory was, that the dioptric light was superior to the catoptric one; whereas it had been asserted that at the South Foreland the former gave no better light than the latter. The reasons assigned by Mr. Campbell and Admiral Ryder were facts to which he could bear witness; and he would add a few words to their remarks, as he himself had inspected the dioptric light at the South Foreland. The refracting portion of the apparatus, as was stated by Mr. Douglass, was constructed at an early date, indeed not long after the first introduction of the cylindrical refractor; it ought not, therefore, to cause surprise that it should be of an inferior description. This, the middle portion of the whole apparatus, as he mentioned in the Paper, constituted in its illuminating value seven-tenths of the whole apparatus; and, further, the single central zone of the refracting portion was equal to half of it in illuminating effect; that was, to seven-twentieths of the whole structure. Now, in the case of the South Foreland light, the refracting portion, especially the central zone, was very inferior, and had never been reconstructed, because it required to be removed for that purpose. Nearly every part of it was doing what formerly characterized the upper and lower divisions of the apparatus; that was, sending valuable light to the sky or to the foot of the tower. Looking at these facts, added to what had been stated by Mr. Campbell and Admiral Ryder, no one would be astonished at finding that the catoptric light, brought to a state of perfection, was equal to a dioptric instrument, which, besides not being provided with an adequate flame, was of a very inferior kind in regard to shape and adjustment; for if the imperfections of the lenses, and the original wrong adjustment of the reflecting parts above and below were considered, it seemed scarcely possible to produce worse effects than what were experienced: indeed, when the light was sent over a large vertical angle, in consequence of imperfection of shape, it did not matter much how the parts were adjusted. The sea would in any case receive only a small portion of the large vertical dispersion. He hoped that he had disposed of the reasons why the dioptric system had not realized in certain lights the merits assigned to it theoretically.

Those who had joined in the discussion had mainly alluded to the rivalry which existed between the dioptric and the catoptric systems; but it had not been his intention to refer to the latter plan in any manner disparagingly. By catoptric apparatus was meant the system of condensing a portion of the luminous sphere of light proceeding from the central source by means of metallic paraboloidal reflectors. He had now to allude to certain proposals which had been made by Colonel Smith. There were two points: one was a suggestion that the metallic reflector should be formed by the revolution of the back portion of a parabola round the vertical axis, which passed through its focus, so as to produce a fixed light over 180°. Now, this might be considered to be the inferior one of the two methods that could be adopted for this purpose. The other method was to cause the anterior portion of the parabola to revolve round its parameter; this being the most effectively illuminating part of the parabola, in consequence of the greater lengths of the focal distances, and the freedom from interception by the burner of reflected light. It was indeed the plan which Bordier Marcet originally devised, and which, to his great disappointment, was superseded so soon by Fresnel's dioptric system of fixed lights.

Another proposal had been made by Colonel Smith. It was for the purpose of producing that which was considered by some a desideratum—namely, to increase the horizontal divergence in the lenticular system. Fresnel proposed, in certain cases, to produce lenticular action by placing outside fixed light vertical refractors, which caused the horizontal condensation. Colonel Smith proposed to fix these vertical refractors within the fixed apparatus, so as still to produce horizontal condensation, but placed so near to the flame that the angle subtended by it at the internal refractors should give the desired angle of horizontal divergence. Now, if this arrangement were adopted, the internal refractors, which were intended to condense laterally, must be cylindrical over the flame, and not vertical; and this cylindrical structure must be cut by two meridian planes, a work which would be troublesome, certainly, but not impracticable. But if the twofold system were adopted, there would be no difficulty in placing outside the fixed light, as Fresnel devised, vertical refractors, which should give by their sections any amount of divergence or convergence. It was not necessary for that purpose to have recourse to an internal structure, which, in addition to the difficulty of its execution, would interpose a most inconvenient obstacle in the service of the lamp. But, in truth, neither of these methods was wanted, whether inside or outside. The desired effect was easily produced by means of a single optical agent, as had been proposed by Mr. Thomas Stevenson. He gave simply to the inner surface of the lens a cylindrical curvature, so that the horizontal section of the inner surface would be a circular arc. By this method horizontal divergence, to any required extent, could be given to a beam of rays, which were before parallel, and at the same time the large proportion of light which would be wasted in its passage through a second optical agent would be saved.

He would now refer to the subject mentioned by Mr. Siemens, who, in alluding to the relative merits of the metallic reflector and the dioptric light, and especially in reference to the two lights at the South Foreland, had made a distinction between the effects of quantity of light and intensity of light. Now, while the source of light remained the same, there could be no difference in the intrinsic nature of the effect produced, and the question of quantity and intensity in relation to each other was simply this:—intensity signified the quantity of light received upon a given unit of surface. If, however, the electric spark were used, it might be an open question, how far the undulations connected with that kind of light might so far differ from those of light caused by the combustion of oil or gas, as to introduce special considerations relating to retardation, or diminution of power, in going through the atmosphere. This was a question quite admissible into the subject; but when discussing the relative effects of the dioptric light and of metallic reflectors, while the source of light remained the same in both cases, the only questions to be dealt with were the loss of light caused by the instrument itself, as ascertained by experiment, and its dispersion in conical beams according to purely geometrical reasoning.

There seemed to be an impression, that the metallic reflectors afforded what was termed a body of light, as distinguished from the effect of dioptric instruments. Now, in a large apparatus such as a 45° segment of a first order revolving dioptric light, the central source of light must not alone be considered, for every part of the apparatus was virtually a radiant point. He was not, however, admitting that size was necessarily an essential element, because, when an observer went to a certain distance, the whole apparatus appeared as a mere point. The effect depended upon the actual quantity of light which the eye received; hence the main points to be considered were—first, the original source of light; then the loss of light caused by the apparatus itself; and finally, the wasteful dilution of light in proportion to the extent of divergence permitted over and above what was wanted for practical purposes. He had seen it stated in the treatises even of scientific writers, that actual size was important in the apparatus, in order that it might subtend a large angle on the sea itself, whereas the whole geometrical portion of the subject related simply to angles within the apparatus, and not to its linear dimensions, as it concerned external angles. He had only referred from memory to what had been remarked during the discussion, but he trusted that he had alluded to most of the points which had been brought forward. There was one, however, which was mentioned by Captain Arrow in regard to revolving catoptric lights; and certainly, if the catoptric system admitted of comparison with the dioptric one, it was in the case of revolving lights. Captain Arrow had specially alluded to the catoptric revolving light at Beachy Head; but Mr. Chance was not aware that, on the south coast of England, there existed any revolving light on the Fresnel system which, by its position, could be viewed in comparison with Beachy Head Light. And he would remark, in regard to the lights on the opposite coast, that neither the Cap Grisnez Light, nor the Calais one, were specimens of the most powerful kind of dioptric revolving lights. He would remind those who knew anything about the light at Beachy Head, that it had the great advantage of not showing a flash more frequently than every two minutes, whereas in dioptric revolving lights generally the greatest interval between the flashes was only one minute. He would rather, in these questions, rely upon accurate observation. There was, indeed, wanting in this country some institution where such points could be decided by actual photometrical experiments, so as to do away with mere conjectures. What was the observation of any mariner worth, when he said that one light gave a powerful effect and another a weak effect, and at the same time gave no particulars concerning the state of the atmosphere? There was nothing so difficult as photometry. The men who handled it under the best circumstances found it difficult to come to conclusions. One rule was indispensable —observations should be simultaneous. It might, indeed, be considered impossible, after looking at any particular light, to remember its intensity. He attached no value to general remarks such as that one light was good and another light bad. It was necessary to appeal to scientific tests, and at present that method was pursued in France alone. The French had carried on from year to year the most systematic course of experiments upon the metallic reflectors and the Fresnel apparatus. Granting that their reflectors were not so good as the English, it was easy to make a deduction for any such difference. What had the most recent experiments proved? That a fixed light of the second order gave an effect equal to that of sixty reflectors of about the ordinary English type. That calculation was not based upon measuring only the brightest part of the beam, but upon the actual quantity of light sent out in a horizontal plane. Take, for instance, a metallic reflector with a horizontal divergence of 15°; the intensity of light relatively to a given unit was measured at each degree, or at each half degree, whence was calculated the total quantity of light contained in the whole angle. In the same manner the intensity of light from the different kinds of Fresnel apparatus was ascertained. It was a matter of simple calculation to compare the quantity of light found in each instrument. The experiments of the French optical Engineers gave results from which it followed that a first order apparatus such as that represented, could be equalled in actual quantity of light in a horizontal plane only by one hundred and eight reflectors of the English type, and by that result he must abide until it was shown to be fallacious by other experiments conducted as scientifically as those made by the French. He wanted to impress upon all that he was merely taking the quantity of light, without regard to its distribution. If this discussion should lead to nothing else than to the institution in this country of some central establishment connected with lighthouse illumination, similar to that at Paris, he felt it would have done great good. Until, however, trustworthy experiments were made in this country, the results obtained in France must be accepted.

Mr. Redman communicated, through the Secretary, the following extracts from an article he had published many years ago on the subject under discussion:—[1]

"The Trinity House have from time to time paid considerable attention to the subject of the different methods of producing light with the greatest effect, and experiments have been made by the Corporation at various periods: in 1827, some were made on the power and brilliancy of Sir David Brewster's lens, the result of which was an impression at that period, that from the small divergence of the light exhibited by Dr. Brewster, it was not so applicable to the purposes of Lighthouses as the common method of Argand burners and reflectors. Various experiments have likewise been made by the Trinity House to test the power of the Drummond light, which for the strength of its flame is probably unequalled, but it has not hitherto been practically made use of on account of its complexity. . . . .

"A Committee of the Elder Brethren have visited the French light of Cordovan. . . . . Experiments have likewise been made at the Trinity House, on the strength and intensity of oil gas; this gas is however more expensive than spermaceti oil, and has only been used for one or two local harbour-lights. Coal gas from the large quantity of fuel required for its production, and the consequent cost of its transport, and also the uncertainty entertained as to the safety of the light, has not been adopted except in a few harbour lights, and even then in some cases has been abandoned. The same remark may be made of the Bude light as of the Drummond, viz., that if the present objections to its adoption are once overcome, it is likely to become a powerful auxiliary to the present system.

"In former years, and indeed until very recently, beacon-lights were of an uncertain and flickering nature, produced by open fires exhibited from the summits of towers, either by the combustion of wood or coal. Many of the existing towers were formerly lighted in this way, until the mode

[1] *Vide* "Remarks on the Lighthouse System of Great Britain: including a tabular description of the principal English Lights." By J. B. Redman. [Tract 8vo., vol. lxxii.] London, 1843.

was abandoned for that of a more stable and certain character. Candles were the next improvement, which we find Smeaton introducing at the Eddystone Lighthouse; and the fact of his recommending them in preference to oil-lamps, shows how little attention at that period had been paid to the subject. The light produced by candles must have been of a faint and varying character, and must have required constant attention in snuffing the wicks; oil had, however, been introduced into Lighthouses previous to the erection of the Eddystone.

"The introduction of Argand oil-lamps and reflectors was a great improvement, giving a steadier, more certain, and more brilliant light, besides affording facilities for the introduction of distinctions between lights, by making use of revolving frames. These lamps were first used about 1780, at the celebrated French light of Cordovan, and soon after by the Trinity Corporation. In Scotland reflectors were introduced in lieu of coal-lights in 1786, and about the same period in Ireland; and the plan shortly became general.

"It is called the Catoptric system, from the fact that the light from the lamps is reflected and thrown forwards from the plated surfaces of the reflectors, which possess the property of reflecting cylindric beams of light in the direction of their axis, and parallel to the horizon. It results from the figure, that although the reflectors are closely arranged on the supporting frame, there are blank spaces between the beams of light, which are only rendered luminous by aberration and divergence. This is of less consequence in a revolving than in a fixed light, and it is the principal fault of this system. To overcome this objection glass lenses were first used in lighthouses, on the south coast of England, about forty years back. In this case the light is refracted instead of reflected, and projected forward in a horizontal beam, the rays of light being refracted or bent from their natural divergent course, and collected into a luminous belt. These lenses were, however, soon abandoned; for, from their imperfect form, and the fact that the lens was formed of one piece of glass, it was of great thickness, and absorbed a large amount of light, and was thus a less perfect instrument than the reflector. To obviate this objection Buffon proposed the grinding of the lens into steps, or concentric rings; but the difficulty of forming a solid piece of glass to the requisite form, prevented the formation of more than a few specimens of this lens. Condorcet first proposed, in 1788, the constructing, in separate pieces, or as it has been termed building of these lenses. Sir David Brewster also appears to have done the same thing in 1811; and in 1822, Fresnel proposed the same method, and, as it is generally supposed, without any previous knowledge of the two former propositions; and to him belongs the merit of first applying these lenses to the practical purposes of Lighthouses.

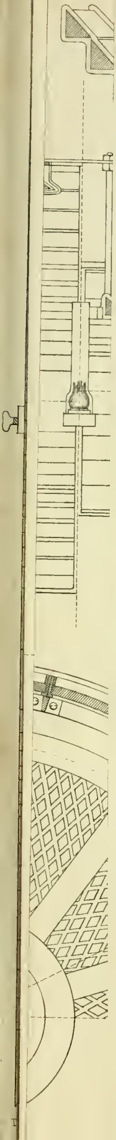
"The term 'annular' has been applied to them from their resemblance to the annular rings of timber. The great advantage obtained from this mode of building lenses is the ease with which a perfect figure is obtained for each zone, and the forming of a larger lens than could be procured from a solid piece of glass, and the fact that it is also materially lessened in thickness. The dioptric light is produced by a single powerful lamp placed in the centre of a frame supporting the lenses, composed of from one to four circular concentric wicks, according to the power of lamp required. These lamps, from the more rapid combustion produced, are supplied more quickly with oil than in the ordinary lamp, by its being forced up and made constantly to overflow the wick, and a very tall chimney-glass is made use of to ensure a rapid draught for so large a flame. The divergence of light from the annular lens is much less than from the parabolic reflector. These larger annular lenses are used for revolving lights, horizontal prisms of the same section being made use of for a fixed light, producing a belt of light equally brilliant in every point of the horizon. A compound light, termed Cata-dioptric, was also introduced by Fresnel, and is, as the name implies, a combination of the two former systems, being produced as well by reflection as refraction, by means of a series of mirrors arranged in circles above and below the frame supporting the lenses, their diameters decreasing as their distances increase from the focal centre. Cata-dioptric prisms are also used for this purpose; they absorb a less quantity of light, and their property is from their optical form to project horizontal rays by total reflection, from the diverging rays falling on their inner surfaces.

"The great advantage of the French lights, as the above are generally called, is the increased brilliancy and equality of effect in all azimuths. They are divided into four orders or powers of light, which are regulated by the relative diameter of frames and number of wicks to the lamp: in those of the first order the interior radius or focal distance is three feet, and the lamp has four wicks; in the others the radii proportionately decrease, and the lamp by one wick to each order. This classification is not intended as a distinction, but to denote the power and range of lights according to the locality and the distance that they are required to be seen. From the experiments that were made in 1832 and 1833 by the Commissioners of Northern Lights, it appears that the light from one of the large annular lenses used for revolving lights of the first order, was equal to eight of the large reflectors used upon the Scotch coast, and the consumption of oil seven to twelve in favour of the French plan. In the introduction of the French lights into the United Kingdom, the following facts are worthy of notice,—that although the French light is superior in some respects to that used in England, there are circumstances which are materially in favour of the latter plan. The superiority of the Dioptric over the Catoptric consists in diffusing over the horizon an uniform belt of light for fixed lights, by which means they may be observed at equal distances from every point of the horizon, which cannot be obtained by any practical arrangement of parabolic reflectors, nor is the characteristic appearance of the fixed light changed by this method; in the revolving light, however, it is worthy of attention, that from the less divergence of the light in the dioptric plan, the characteristic appearance of the revolving light so well known is materially altered, and the management of the mechanical lamp is rather uncertain—the French revolving lights from this cause having at times been extinguished. In stationary lights, where the whole circle is not illuminated, this objection does not hold good, as the fountain lamp can then be introduced; and even if the mechanical lamp is used, from the greater simplicity of construction the lamp is of more easy access, and the mischief sooner remedied; but both in the revolving and the fixed light there is this objection to the single lamp, that in the event of its going out the navigation is completely deprived of the light; whereas the extinction of a lamp in the Catoptric light involves only a lesser evil, viz., the reduction of brilliancy in the light. There is another peculiarity attendant on the French light; it is this, that from the fact that there is so little divergence of light, the atmosphere below as well as above the belt of light is completely obscure, and when the light is of a local nature it might be approached so close as to be completely obscured. Notwithstanding these objections, however, the French light has been introduced in many instances in Great Britain, and is likewise being adopted in other countries."

May 14, 1867.

JOHN FOWLER, President,
in the Chair.

The discussion upon the Paper No. 1,180, "On Optical Apparatus used in Lighthouses," was continued throughout the evening, to the exclusion of any other subject.



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