MÉMOIRE

SUR

UN NOUVEAU SYSTÈME D'ÉCLAIRAGE DES PHARES;

PAR M. A. FRESNEL,

INGÉNIEUR AU CORPS ROYAL DES PONTS ET CHAUSSÉES, ANCIEN ÉLÈVE DE L'ÉCOLE POLYTECHNIQUE;

LU À L'ACADÉMIE DES SCIENCES, LE 29 JUILLET 1822.

A PARIS,

DE L'IMPRIMERIE ROYALE.

1822.

MEMOIR

upon a

NEW SYSTEM OF LIGHTHOUSE ILLUMINATION

There has existed for several years a Commission of Lights, the members of which were chosen from among the most distinguished scientists and the inspectors of the Royal Corps of Engineers des Ponts et Chaussees. Charged with devising a general project for the distribution of lighthouses upon the coasts of France, they sought at first to determine whether the system of illumination already in use could not be improved. Several interesting experiments had already been made upon the brilliancy of the light produced by small wicks placed in large Lenoir reflectors; but other duties, with which a majority of them were charged, prevented them from devoting the necessary time to these investigations. In 1819 M. Arago offered to take charge of these experiments, provided M. Mathieu and myself were allowed to assist him. This proposition, adopted by the Commission, was submitted to M. Becquey, Director General des Ponts et Chaussees, who also approved it, and desired me to devote the greatest care to these investigations. A wish to be worthy of his confidence, and of that of the Commission of Lights, as well as the importance of the subject, induced me to devote all my attention to these investigations.

From the very first I thought of substituting large glass lenses for the parabolic reflectors. We know that, like a parabolic mirror, a lens has the property of parallelizing the rays of light that issue from its focus and pass through it; it produces, by refraction, the same effect that a parabolic mirror does by reflection. This application of lenses to lighthouse illumination could scarcely be regarded as a new idea; it would readily occur to any one, and there is, indeed, now in England such a lenticular apparatus but it appears that it gives very little light, which is probably due to the great thickness of the lenses employed, (0.20 of a meter,) and perhaps also to the general arrangement of the apparatus, upon which point I have no very precise information.

If the thickness of the lens does not exceed the ordinary thickness of plate-glass, the amount of light absorbed by it will be very small as compared with that which passes through; the loss resulting from partial reflection on the two surfaces is only one-twentieth, according to the experiments of *Bouguer*; but even supposing it to be one-twelfth, it is readily seen how little the light will be reduced in intensity by its passage through such lenses, and what advantages they would have in this respect over the best metallic reflectors, which absorb one-half of the light when the angles of incidence are slightly oblique, as is always the case with the greater portion of rays, in a parabolic mirror. This consideration led me to hope that I could economize the light considerably by substituting lenses for parabolic mirrors.

Some transparent liquids, such as water and spirits of wine, absorb only a small portion of the light that passes through them, even though the thickness be 0.20 or 0.30 of a meter and it might be supposed that large lenses made by enclosing a liquid between two shells of glass might be used in lighthouses; but, besides the great weight of such lenses, which would tend to rapidly wear out the machinery which gives a rotary motion to the apparatus of eclipse lights, the long continuance of these liquids in the cases would cause the interior to become tarnished, and it would be very difficult to clean them. The mastic used for uniting them might crumble away at some points along the edges and allow the liquid to escape. It was, therefore, much better to avoid these difficulties by employing solid materials.

It was also necessary, in order to avoid too great a loss of the rays emitted by the light placed at the focus, that each lens should embrace all the rays included in an angle of 45°, and it then follows that the prismatic angle of the glass at the edge of the lens should be 40°. It will readily be seen that the glass at the center would be very thick if the lens were terminated on the outside by a continuous spherical surface. This great thickness would have the double disadvantage of very much reducing the intensity of the light passing through it and of rendering the lens entirely too heavy.

But if the exterior surface of the lens be divided into concentric rings, and if, from the small lens in the center and the rings which surround it, all the useless portion of their thickness be removed, leaving only enough to permit of their being solidly united at their thinnest edges, the parallelism of the rays emerging, from the focus can also be obtained, or, what is the same thing, rays parallel to the axis of the lens and falling on the outside, can be united at the focus by giving to the surface of each ring the proper inclination and curvature.

Buffon was the first to suggest echelon lenses for increasing the power of burning-glasses while diminishing their thickness; but, from what he said on this subject, it is evident that he proposed to make them of a single piece of glass which would render their fabrication almost impossible, especially when of large dimensions, on account of the difficulty of cutting away the glass and smoothing and polishing the surface where such projecting edges are presented. He expresses himself in regard to it as follows:

> "I then endeavored to devise some means of overcoming this difficulty, [that of the too great thickness of the glass,] and I found a simple and easy manner of diminishing the thickness of the lenses to any desirable extent without sensibly diminishing their diameter and without lengthening their focal distance.
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> "This consists in cutting my piece of glass into steps. In order to make myself better understood, let us suppose that I wish to

diminish to *one inch* the thickness of a glass lens which is twenty-six inches in diameter, has five feet focal distance, and is three inches thick at the center. I divide the exterior curved surface of the lens into three parts, and move each of these parts toward the center of curvature until there remains but the thickness of one inch in the center of the lens, a step being formed on each side by moving the corresponding parts an equal amount. Then, by making a second step, I reach the extremities of the diameter, and have a lens in steps, (à echelons,) which has about the same focal distance, the same diameter, and is only about one-third as thick as it was at first, which is a great advantage.

"If a piece of glass *four feet in diameter by two and one-half inches thick* be first molded and cut into steps (echelons) for a focal distance of eight feet, I have estimated that, leaving it even one and one-half inches thick at the center of the lens and the same at the interior edges of the steps, the heat from it [used as a burning-glass] will be to that of the Palais Royal lens, as 28 is to 6, without taking into account the effect due to the difference of thickness, which is very considerable, and which I cannot estimate in advance.

"This kind of refracting mirror is in every respect the most perfect of its kind; and even if we reduce its diameter to three feet and its thickness to fifteen lines[1] at the center and six feet focal distance, which will render its fabrication much less difficult, a degree of heat can be produced which is at least four times as great as that of the most powerful lenses known. I dare say that this echelon mirror would be one of the most useful instruments in *physics. I invented it more than twenty-five years ago,* and all scientists with whom I have spoken about it desire that it should be made. It will be of great service in the advancement of science; and applying a heliometer to it we could conduct at its focus all chemical operations as easily as in the fire of a furnace," &c.

This quotation sufficiently proves that *Buffon* had not thought of constructing his lenses in several pieces, since he made their

[1] A line is equal to 0.09113 of an inch.

construction depend upon the casting of a piece of glass *four feet in diameter by two and one-half inches in thickness,* which he proposed afterward to reduce to *three feet in diameter by fifteen lines in thickness, in order to render its fabrication more easy.* Now, by making these lenses in several pieces, it is as easy to construct one of four feet in diameter as of three feet, even if the focal distance be-much shorter than *Buffon* supposed. It is easily understood why, twenty-five years after having invented these lenses and notwithstanding his earnest desire to possess one, the same scholar who invented the beautiful mirror of Archimides, the construction of which was much more complicated and much more expensive, was unable to procure an échelon lens three feet in diameter, it was because he had not thought of making them of several pieces. Moreover he did not, apparently, perceive a great advantage offered by the separate fabrication of each ring, namely, the almost complete correction of spherical aberration by using a sufficient number of rings and generating their exterior surfaces by arcs having proper radii of curvature; because, after considering the original lens as terminated by a continuous spherical surface, he proposes that it be depressed in steps, but so that the portions of the new spherical surfaces should be concentric with the first, which is not the true way of correcting spherical aberration. We find, by calculation, that the generating arcs of the rings not only ought not to have the same center, but that their different centers should not be situated upon the axis of the lens, and that they depart from it in proportion as the arcs to which they belong are more distant from the center of the lens; so that these arcs on being revolved about the axis do not generate portions of concentric spherical surfaces, but surfaces of the kind known to geometricians as annular surfaces.

It may seem strange, perhaps, that I dwell at such length on these simple reflections. It is undoubtedly very easy to imagine lenses composed of several pieces, and to deduce from the ordinary laws of refraction the most suitable form for the surface of each ring. But it is also easy to invent lenses with steps, as I know from my own experience, because I did not know what Buffon had published upon the subject when I proposed for the first time to the Commission of Lights the construction of such apparatus. It was M. Charles who informed me that this invention was not new, and he showed me the chapter of the supplement to the Natural History where it is described. Having thus lost a part of what I had invented, I may be excused for showing some solicitude for the preservation of the little that is left me, especially when it is precisely that which renders the invention practicable on a large scale.

These ideas—of the lens in steps and of forming it of separate pieces—were not the fruit of long study; they are so simple that they readily occur to the mind. What occupied me most was the means of executing them, in this I have been ably seconded by the zeal and intelligence of M. Soleil, the optician, who bravely undertook the construction of these large lenses.

As only spherical surfaces can be made by the ordinary process in basins, I first divided each ring into a sufficient number of pieces, and then calculated the curvature and the inclination of the small portion of a spherical surface that I substituted for the corresponding part of the annular surface, in such a manner that the spherical aberration would be the least possible. These calculations were longer and more tedious than those, which would be required for determining the elements of annular surfaces. I hoped to afterward make the latter, but in order to have, as soon as possible, a large lens with which to make experiments as to its adaptability to lighthouse illumination, it was necessary to employ the means that M. Soleil had at his disposal. That determined me to substitute, for the time being, for each annular surface an assemblage of small portions of spherical surfaces, and even to give to the rings the form of a polygon, instead of a circle, as it was more easy to work pieces of the glass in straight lines.

In order to unite all the pieces which compose the lens, I thought at first of fastening them upon plate-glass by means of thickened Venetian turpentine, which M. Cauchois had employed with success in gluing the object glasses of a telescope, and which was not likely to become spotted as soon as drop mastic. But experience has shown that the heat of the sun would melt it and cause it to run at the joints. Strictly speaking, I might have been able to prevent this by closing the joints with cement. Nevertheless, it appeared preferable to fasten the pieces of glass to each other at their edges by means of a strong glue, because, in this manner, the transparency of the lens would be wholly independent of any changes in the material with which they were united. In the place of Flanders glue, we employed, after consultation with M. Arago, fish glue; its strong adherence to glass being well known to him, as he had vainly endeavored to separate, in boiling water, two prisms which had been united by it. It was not because glue of ordinary strength does not adhere sufficiently to the glass; in fact, it sometimes happens that, when removed without proper care, it carries with it small splinters of the glass; but fish glue, which probably possesses this quality to a larger degree still, has the advantage of being clearer and less brittle.

In place of making the pieces of glass composing the lens curved on both sides, that is, making them double convex, I made them plano-convex, in order to simplify the making and render easier the cementing of the edges; they can then be placed flat side down upon a marble table covered with a sheet of paper, and be left there for any length of time necessary for the glue to dry. On the other hand it would be difficult to unite by the edges a large number of pieces of glass of the double-convex form.

Following out the process that I have just described, M. Soleil succeeded easily in constructing a large square lens 0.76 of a meter on the side, its form and dimensions having been determined so that it could be made a part of an illuminating apparatus which I had devised, and which would greatly surpass the luster of the most brilliant lighthouses; as M. Arago, M. Mathieu, and myself were convinced from our preliminary experiments upon a smaller lens only 0.55 of a meter square.

As soon as experiments had demonstrated to the Commission of Lights the advantage of the new system of illumination, M. Becquey, after having assured himself of the superiority of the large lens over parabolic mirrors, ordered the construction of an apparatus composed of eight such lenses. I engaged M. Soleil to try to make one with annular surfaces instead of composing each ring of small portions of spherical surfaces. I attached great importance to this improvement, not only for lighthouses, but also for burning-glasses, in which it is still more essential to completely correct the effects of spherical aberration. At that time I indicated to M. Soleil the mechanical process that he has since definitely adopted, and which he now employs with success.

In the execution of lenses designed for the illumination of lighthouses, it is not necessary to attain a very high degree of accuracy, but, nevertheless, the substitution of annular surfaces for the assemblage of small portions of spherical surfaces produces a sensible increase in the light thrown out in the direction of the axis. Besides, the technical process by which annular surfaces are formed allows the construction of large lenses with much greater rapidity**,** than when we were obliged to work separately in the basins, the ninety-seven pieces of which each polygonal lens was composed. The number could not have been diminished without increasing at the same time the spherical aberration, while, in the annular lenses, there is no disadvantage in diminishing the number of pieces which compose each ring; in fact, there would even be an advantage in making it of a single piece, provided it could be done, because the multiplicity of these divisions always causes a small loss of light, and is less favorable to the solidity of the apparatus. On account of these considerations, presented by M. de Rossel and M. Arago, M. Becquey ordered, last year, the construction of eight annular lenses designed for the illumination of the Cordouan lighthouse, in order to encourage this new branch of industry, and that M. Soleil might be induced to have the necessary machinery constructed.

The grinding of the rings has become much less tedious since this optician, in place of being obliged to rework his pieces of glass, receives from the manufactory of St. Gobain large arcs run in molds, the forms of which more nearly approach their finished condition, than did the pieces reworked by him.

This favor was kindly accorded to M. Soleil by the manufacturers, at the request of the Commission of Lights, and the accomplished Director of the establishment, M. Tassaert, has taken great interest in the successful casting of our curved prisms. Nevertheless, they are not as free from striae, and especially from bubbles, as plate-glass carefully remolded. It appears that when pieces of cast-glass are more than eighteen inches in length and two or three inches thick, it is very difficult to preserve them entirely free from bubbles and spots. Flint-glass, or glass with lead in it, is less liable to bubbles, but it has the disadvantage of being more liable to striae; besides, it is much heavier than the crown-glass of St. Gobain, it is principally for the last reason that we prefer the latter, notwithstanding its decided greenish tinge; besides, the latter is harder and less liable to be affected by the air than glass in which there is much oxide of lead.

Our large lenses, 0.76 of a meter square, which subtend at the focus both horizontally and vertically an angle of 45°, show on the outside, from the center to the middle of either side, six steps or échelons, including the center lens, and ten steps or échelons from the center to either corner; and the most salient ring has only a maximum thickness of 0.037 of a meter;[2] and the weight of the lens, including a strong copper frame, does not exceed 75 pounds. In order not to load too heavily the machinery by which rotary motion is given to an apparatus composed of eight lenses, it was necessary to reduce the weight as much as possible by increasing the number of steps. The width of the rings was determined so that their projecting angles should vary as little as possible.

Having described the construction of these large lenses, I propose now to explain how they are arranged in the apparatus, which is to serve for the illumination of lighthouses. Of all the combinations of lights, of lenses, and reflectors that I have thought of, the following appears to possess superior advantages. All the light intended for the illumination of a lighthouse is united in one single flame. This flame is surrounded by eight square lenses set vertically, the centers of which are situated in the same horizontal plane as the single light, their distance from the flame being equal to the focal distance of parallel rays, they thus form around the brilliant object a vertical prism having a regular octagonal base; and, as each embraces an angle of 45° in a horizontal and vertical direction, they receive and transmit the luminous rays comprised in an equatorial zone of 45°, belonging to a sphere which has its center at the

[2] The angle pieces are not thicker than 0.04 of a meter.

common focus of these lenses. Now this zone comprises 0.383 of the surface of the sphere, or about two-fifths; and if we suppose that the intensity of the light is diminished one-tenth by its passage through the lenses, there will still remain 0.34, that is to say about one-third. It is probable that the loss of light may be a little more, but, on the other hand the lower part of the luminous sphere receiving much less light than the rest on account of the opacity of the lamp-burner which holds the wicks, the equatorial zone of 45° will actually contain more than two-fifths of the total light emitted; thus there is undoubtedly no exaggeration in estimating the total amount of light refracted by the lenses at one-third the total emitted.

Reflectors have the advantage of enveloping, so to speak, the brilliant object, and of receiving a larger number of rays; but they absorb at least one-half. Parabolic reflectors embrace ordinarily, about seven-tenths of the total surface of the luminous sphere, but this fraction should be reduced to six-tenths on account of the burner, which intercepts many rays in the lower part of the reflector. Consequently one-half of the light being absorbed by the mirror, the sum of the rays that it reflects is equal to three-tenths of those emanating from the focus—in other words, a little less than the sum of the rays transmitted by the lenses.

The useful effect of the lenses and the reflectors does not depend alone upon the proportion of the refracted or reflected rays, but on their greater or less concentration in the horizontal plane where the light will be useful to mariners; this depends upon the relation between the dimensions of the brilliant object and the distance from the focus to the various points on the surface of the mirror or lens. In the lenticular apparatus that I have just described this distance varies but little, it is 0.92 of a meter from the center of the lenses, one meter to the middle of their edges, and 1.07 meters to their angles. In a parabolic reflector, on the contrary, the distance from the focus to the various points of the surface varies from one to three and one-half; and to the extremity of the parameter it is double what it is to the summit of the paraboloid. In the largest reflectors yet employed, which have an opening of thirty-one inches and weigh nearly one hundred pounds, the distance from the focus to the summit of the paraboloid is only 5 inches. The vertical divergence of the rays in that half of the luminous sphere nearest the summit will, it is seen, be great, even when the flame which illuminates it is only one and one-half inches in height. A part of these diverging rays are, without doubt, usefully employed in illuminating the vicinity of the lighthouse, but the rays which pass out above the horizontal plane are absolutely of no use whatever. As the intensity of the light decreases proportionately to the square of the distance, it is to the most distant points of the horizon that the greater portion of the rays should be directed, and it is not necessary to reserve much of the light to illuminate the near vicinity of the lighthouse.

It is, therefore, by the sum of the rays directed in a horizontal plane that the comparative effects of illuminating apparatus for a lighthouse should be judged; and it is in this respect that M. Arago, M. Mathieu, and myself have compared the useful effects of reflectors and large lenses.

It would be very disadvantageous if the central light in lenticular apparatus was formed by an assemblage of a large number of ordinary Argand burners, because if they were only ten in number the loss of light from each, due to the interception of rays by the others, would be considerable. The intensity of the light being the most essential quality in a lighthouse, it was necessary, in order to make the most advantageous use of the lenticular apparatus, to produce a central light of great brilliancy and of small dimensions. M. Arago and myself have succeeded in solving this problem in a satisfactory manner by carrying out the idea of M. Rumford in regard to multiple wicks, and we have been even more successful in our trials than he was. We have had constructed burners with two, three, and even four concentric wicks, which can be managed almost as easily as an ordinary burner. We have completely succeeded in protecting the burner from the great heat developed by causing an overflow of oil, as is done in the Carcel lamps; and this arrangement has succeeded so well that notwithstanding the great number and duration of the experiments in which these burners have been tested, we have not yet been obliged to clean them. These large burners have not, as have those hitherto made with a single cylindrical wick, the disadvantage of giving a reddish flame of little height. Their light is as white as it is brilliant; and the concentric flames mutually heating each other are lengthened with facility, it is even necessary to keep the chimneys up a little in order that the air, which is rapidly renewed may be sufficient for the combustion of the disengaged gas, and, cooling the burner, prevent the too rapid distillation of the oil.

It might be feared that the rapidity of combustion would char the concentric wicks (especially when a four-wick burner is used) more rapidly than occurs with the ordinary single-wick burner, but experience has demonstrated the contrary; and we have, besides, found that wicks of the four-wick burner waste less rapidly according to the effect they produce than the others, which is undoubtedly due to the great heat developed, facilitating the rise of oil in the wicks. We have kept the four-wick burner lighted for fourteen hours together without trimming, and the intensity of the light given by the lens which it illuminated was scarcely diminished one-sixth of its first intensity. Thus the four-wick burners may burn throughout the long nights of winter without, requiring to be trimmed; it is sufficient to raise the wicks a little toward morning in order to preserve the flame at the height it was in the beginning.

The four-wick burner, 0.09 of a meter in diameter, burns nearly one and a half pounds of oil per hour when combustion is most active, and gives a light in proportion to the quantity of oil consumed; it is equal, as regards expense and the light produced, to seventeen Carcel burners. It is with this burner, placed in the center, that the illuminating apparatus composed of the eight large lenses, 0.76 of a meter square, is lighted. The lamp is fixed upon a table resting upon a cast-iron pedestal, which also supports the weight of the lenticular apparatus. This apparatus can easily be turned around its axis on the column by means of rollers, which move upon a circular projection on the top of the pedestal; it is put in motion by means of clock-work, which also regulates its velocity. In thus revolving around the central light, which is fixed, the lenticular apparatus throws out successively, upon all points of the horizon, the eight luminous cones from the lenses, separated by intervals of darkness; thus producing, to a distant observer, the appearance of a regular succession of flashes and eclipses. The angular extent of each flash, with a light of sufficient brilliancy to be seen at a distance of six leagues, being only 6.5°, while that of each interval of darkness is 38.5°, the duration of the flashes will be only one-sixth that of the eclipses. This will be ample, however, as it is still less in most of our lighthouses provided with flashing reflector lights. There are even some where the duration of the flashes is scarcely one-tenth that of the eclipses. Nevertheless it was desired that we should increase the relative duration of the flashes in the lenticular apparatus, as mariners generally find that the eclipses are too long.

It is easy to increase, to any desired extent, the divergence of the emergent rays by shortening or lengthening the distance of the lens from the central flame; but as the divergence in a vertical plane is increased in the same proportion as the horizontal divergence many of the rays would be lost, and the intensity of the light diminished in a much greater proportion, than the duration of the flashes would be increased. Thus, if by this means we double the duration of the flashes, their intensity is reduced to one-quarter of that which they had at first. In employing lenses with a shorter focal distance, the same disadvantage would occur, but the weight and cost of the apparatus would be diminished.

I propose to increase the duration of the flashes without diminishing their intensity and without increasing either the size of the illuminating body or the expenditure of oil. I accomplish this easily, without changing any of the general arrangements of the eight lenses, by utilizing the rays passing out above them, which would otherwise be lost. For this purpose I employ eight additional trapezoidal lenses of 0.50 of a meter focal distance, which are placed above the four-wick burner in the form of a truncated octagonal pyramid, like a dome or roof, through the upper opening of which the chimney of the lamp passes. These lenses embrace one-fourth of the surface of the sphere which has its center in the common focus of the large lenses, and therefore receive more than one-fourth of the total amount of light emitted from the flame; since the upper hemisphere, as we have already observed, contains more light than the lower. But as we are obliged to employ silvered mirrors to reflect in a horizontal direction the luminous beams which pass through these lenses, a large part of the incident light will be absorbed notwithstanding their decided inclination, which is 25°; and I estimate that the incident light will be reduced one-half by its passage through the lenses and its reflection from the mirrors; hence the quantity of rays thus utilized is scarcely one-eighth of the total emitted from the flame of the four-wick burner. However, by so placing these additional lenses that a plane through their centers and the axis of the apparatus will make, with a corresponding plane through the centers of the large lenses, an angle of 7°, the duration of the flashes is at least doubled. It is necessary that the light from the small lens should precede that from the large one; for, if it followed it, the eye of the spectator would be fatigued by the brilliancy of the great flash, and would not see the other as distinctly.

The light transmitted from the small lenses is, without doubt, very inferior to that sent out by the large ones; first, because their area is only one-fifth of the latter, and second because the rays are reduced in intensity by reflection on the mirrors. Nevertheless they are of sufficient intensity to be seen at a considerable distance. Observations made at a distance of 25000 meters, on a moonlight night, show that the additional lenses double the duration of the flashes; and it is probable that they would be prolonged nearly as much at a greater distance. These small lenses, which, with their mirrors, only increase the price of the apparatus 2700 francs and its weight only 128 kilograms, are therefore very useful, and even economical, since they collect and throw out, in a direction useful to mariners, a large portion of light that would otherwise be lost.

We can, strictly speaking, also direct toward the horizon the rays which pass out below the large lenses, but it would be difficult to do this without interfering very much with the service of the lamp, so I have decided to allow them to fall directly on the sea, where they will not be entirely useless, as with their plunging rays they light up the near vicinity of the lighthouse.

M. Arago, M. Mathieu and myself have compared in numerous experiments, the intensity of the light from lenses 0.76 of a meter square, with Lenoir reflectors having an opening of 31 inches, and with the double paraboloidal reflectors of Bordier-Marcet, 28 to 29 inches in diameter, the largest that have ever yet been employed for lighthouse illumination. We find that the lens illuminated by the four-wick burner gives, in the direction of its axis, a light three and one-fourth times as brilliant as that of the great Lenoir reflector, and four and a half times that of the double paraboloidal reflector of Bordier-Marcet. For the best revolving lights, we ordinarily use only two large reflectors,[3] pointing in the same direction and the apparatus is composed of four such pairs set on the vertical faces of a rectangular prism; the flashes thus produced by the lenses are twice as brilliant in the axis as those of the Bordier-Marcet, or even the Lenoir reflectors, as it is almost impracticable to establish a sufficiently exact parallelism between the axes of the separate pairs of reflectors, so that the intensity of the two shall be double that given by either separately; this is especially true when such large reflectors as those of Lenoir are illuminated by small burners six lines in diameter. It is besides necessary, on account of the slight width of the luminous cones, to give to their axes a slight divergence in order to prolong the duration of the flashes, and consequently, the flashes produced by the large lenses must have twice the intensity of those of the best illuminated lighthouses in France.

In order to compare the total amount of light in the flashes of the lenticular apparatus and reflectors, we measured the intensity of the light in many different directions, from the axis out to the extreme limits of the flash, by successively pivoting upon a revolving table the lens and reflectors, and comparing the light to that of an ordinary lamp taken as unity by the method of shadows; then multiplying each partial intensity by the small corresponding angle described in the rotation, we obtained numbers showing their relative useful effects. We thus found that the sum of the rays of the entire flash of each reflector was not one-third the sum of the rays in the flash of the lens provided with a four-wick burner.

[3] In the light-house of Cordouan there are four great reflectors upon each of the three faces of the apparatus which forms, instead of a square, a triangular prism; but it appears that a considerable divergence is given to their axes in order to prolong the duration of the flashes, for this light is no more brilliant than the others.

Thus, for the total effect, each lens of the new apparatus was equal to three great reflectors of Lenoir or Bordier-Marcet.

As to the quantities of oil consumed, we find that the apparatus composed of eight large lenses illuminated by a four-wick burner is almost as economical[4] as the large Lenoir reflectors with a small burner, and is twice as economical as the large reflectors of Bordier-Marcet, which have each two burners of ten lines diameter. Now we have not yet considered in our calculations the effect produced by the small additional lenses, which increase the duration of the flashes without increasing the expenditure of oil. We see, then, what very satisfactory results are obtained by lenticular apparatus; since, with the same consumption of oil, it gives an effect three times as powerful as that of an apparatus composed of eight large reflectors illuminated with the smallest burners; the weight and cost of the apparatus being only slightly increased. The weight is increased one-eighth and the price about three-fifths.

But, another very important advantage, which will suffice to give the preference to lenses, even though their effect should not be superior to those of the reflectors, is the permanency of the glass and the durability of its polish. The cost of keeping the lenses in order will be almost nothing, and their cleaning will give much less trouble than reflectors, which must be frequently rubbed with red oxide of iron to keep up their polish. The lamp being at the center of a lenticular octagon, the inscribed circle of which has a radius of 0.93 of a meter, the lenses will not be as liable to become tarnished with oil as the reflectors are; it will therefore be ordinarily sufficient to dust them lightly with a feather duster, and they will rarely require wiping. When this is necessary it will be well to sprinkle rouge on the linen cloth or chamois skin used for the purpose. In this manner they can be preserved almost indefinitely in

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[4] There is still greater economy in the use of light if we substitute a three-wick for the four-wick burner, because the brilliant object is smaller relatively to its focal distance, and a less number of the rays is lost; but the intensity of the flash is also diminished, and especially its duration, and perhaps there would not be enough plunging rays. I think that a three-wick burner should only be used for lighthouses of the second order, diminishing the focal length and the dimensions of the lenses.

the same condition as when they leave the shop of the optician, while silvered mirrors quickly lose part of their polish, and the cleaning of the eight large reflectors being a work occupying considerable time, it will often happen, through the negligence of the keepers, that they will not be as bright as they ought. Finally, it is necessary to re-silver them from time to time when by friction the silver leaf on their interior surface wears off. The lenses require no such repairs.

As in a revolving lenticular apparatus the central light is fixed, it is as easy to illuminate it with gas as with oil. If it be found economical or otherwise advantageous to do so, it will only be necessary, to replace the lamp by a tube, surmounted by a burner arranged for concentric flames, and communicating at the lower extremity with the gasometer.[5] In the end, all the improvements that time and experience may develop in the production of light can be with the greatest facility applied to lenticular apparatus.

Having shown the principal advantages of this apparatus, I now propose to consider its disadvantages. The first that strikes us is the brittleness of glass; but I will call attention to the fact, that the pieces of glass that compose the lenses are sufficiently thick to prevent their being broken or detached except by a violent shock; and, with a little attention, it is easy to avoid these accidents, which, besides, are easily repaired by means of fish-glue, unless the broken pieces are too small. In such a case it would be better to replace it by another lens and return the damaged one to the lenticular optician for repairs. But, as I have just said, such an accident would, with a little attention on the part of the keeper, rarely occur; and only because it is necessary to provide against

[5] M. Arago and myself intend soon to try a burner of this kind, having six concentric flames, with gas produced by the distillation of coal. If we employ gas made from oil, which gives a more intense light, it is probable that four or five flames will suffice. The distillation of bad oils and other fatty matter being more simple than that of coal, appears preferable for lighthouse illumination; but before applying it, it will be well to ascertain why the English have not made use of it in their lighthouses with fixed lights, and to be assured that it can be economically made in France. Finally, if we employ gas made in any manner, it will be necessary always to have in the lantern a spare lamp, to be used in case it should fail from any accident. The illumination by gas would have this advantage; during the longest nights the flames would be of a uniform height without requiring any care on the part of the keeper.

all possible contingencies need an additional lens, like the one of the eight composing the apparatus, be kept on hand to replace one that might become damaged.

The fact that but a single lamp illuminates the apparatus might occasion some uneasiness because if it should go out the lighthouse would be in total darkness, and vessels which an unfortunate chance might have led into the vicinity, might be cast upon a shoal that the light was intended to mark. But, while a violent puff of wind has sometimes extinguished all the lights of a reflector apparatus, it would not produce the same effect upon the flames of a four-wick burner, which by reason of their size and the activity of the combustion are much less sensitive to currents of air than those of an ordinary burner, as I have often had occasion to remark; for the same reason the wind which will put out a candle will not extinguish a torch. In truth, the "four-wick burner might be extinguished by another cause—namely, the failure of the oil. But, in order to weigh well this danger, which I have carefully considered; it is necessary to understand how the oil reaches the burner.

In order to render the service more easy and to keep the crown of the burner continually wet with a considerable overflow of oil, I have decided, after consultation with M. Rossel and several other members of the Commission of Lights, to apply to this lamp the ingenious idea of Carcel, and to make the oil rise in the burner by means of pumps driven by clock-work. In order to insure regularity and certainty of motion, this clockwork is moved by weights that descend through the interior of the cast iron pedestal, which supports the lamp and service-table. Clock-work as simple as this and driven by weights is not liable to stop, but should this accident happen, or should the valves or plungers of the pump burst or get out of order, another lamp with a clock-work movement, but in which the motor is a spring, would be immediately lighted and substituted for the first. The mechanism of these lamps was devised and executed by M. Wagner, jr., with his usual skill.

As it might still be feared that the keeper might be asleep when the lamp got out of order, I have sought a means for awaking him when the oil stops flowing, and have found a very simple way of doing it; it consists in placing between the burner and the reservoir into which the overflow of oil falls a small tin cup attached to one extremity of a lever, and balancing, when full of oil, a counterpoise weight on the other. This little cup is pierced with a hole large enough to soon empty it when the overflow of oil stops, but not sufficiently large to discharge more oil than is received from the burners when the apparatus is working properly; so it always remains filled as long as the overflow is not diminished in quantity. But, when the oil stops flowing, and before the light is extinguished, the cup empties, the counterpoise drops, and the motion of the lever disengages the spring of an alarm-bell. The noise of the bell continues for some time, and is sufficient to awaken the keeper.

It will not, perhaps, be useless to take still another precaution, by placing near the four-wick burner, and at the same height, the burner of an ordinary Carcel lamp which shall be kept lighted all night, so that, in case the former should fail in its supply oil through any derangement of the pumps, and the keeper not be awakened soon enough to light the spare lamp before the other goes entirely out, the lighthouse will still be illuminated by the light from an ordinary Carcel lamp. The flashes thus produced would undoubtedly be much less brilliant and of shorter duration than those from the four-wick burner, but the light could be seen some distance, and would suffice to warn mariners who might at the moment be near the lighthouse. This Carcel lamp, which the keeper could take up at will and easily carry in one hand, would also be useful in going about the place at night and looking for such things as might be needed.

We think that with these precautions, the new system of illumination will be at least as reliable as that of the system now in use. In very cold nights there is less danger of the oil congealing than in an ordinary lamp, since the tepid oil which constantly overflows into the reservoir from the crown of the four-wick burner, and the proximity of the flame will always suffice to keep in a liquid state the oil in the reservoirs. The service of the four-wick burner is certainly somewhat more complicated than that of the ordinary one, but we are assured from a great number of experiments that but little attention is required to regulate the flames and keep them at the proper height. It is, besides, the only burner that the keeper has to attend; his attention is not divided, as with other apparatus, between eight, sixteen, or even twenty-four burners. There are no reflectors to polish, no burners covered with burned oil to be cleaned. It is only necessary during the day, to trim the wicks, renew the oil in the reservoir of the lamp, and draw the curtains around the apparatus to intercept the solar rays; the latter, without this precaution, might set fire to or melt anything placed at the focus of the lenses. The same precaution is taken when parabolic reflectors are used. The curtains will also serve, during the day at least, to keep out dust.

It is thus seen that the service will be very light. I am persuaded that the lightkeepers at stations where the new apparatus are placed, will be more than satisfied by the simplification of their duties, and that, having no longer to divide their attention among a number of lamps, the light of the single lamp confided to their care will be improved.

Should experience develop, in this lamp some defects which we have not remarked, it would be no reason for abandoning the lenticular apparatus, which presents so many advantages, for it will always be possible to perfect the mechanism of the lamp and obtain, at last, either with oil or gas, the central light necessary for the illumination of the apparatus.

Lenticular apparatus to show a fixed light can also be made, and it will be superior to the illuminating apparatus composed of parabolic reflectors; but, as fixed lights should illumine simultaneously the entire horizon, the same range cannot be had as in revolving or flashing lights, and as they might also be mistaken for others which, through accident or evil intention, might be shown on the coast, the Commission of Lights thought it better to employ only flashing or revolving lights, if their appearance could be sufficiently diversified. We have already partly succeeded in this by varying the periods of revolution of the different apparatus; but this cannot be done to any great extent, for the intervals between the flashes must be strikingly different in order that the sailor of the small coaster may not mistake them, and, besides, the velocity of rotation cannot be varied much without attendant disadvantages. The placing of panes of colored glass before the lenses or reflectors is another means of diversifying flashing lights, but the Commission of Lights doubted whether this plan was certain to give satisfactory results, and it has the disadvantage of occasioning a great loss of light. For this reason I have sought to attain the same end, by so arranging an apparatus, that the intervals between its flashes shall be of unequal periods according to the idea of M. Sganzin, Inspector General des Ponts et Chaussees. The first lenticular apparatus made by M. Soleil was on this plan; two of the eight large lenses being each replaced by two of half width, embracing an angle of 45° in a vertical, but only 22.5° in a horizontal direction, and set on opposite sides of the apparatus. The result of this arrangement is, that the angular intervals between the middle of the successive flashes, and consequently the corresponding intervals of time, form the periodic series 1, 1, ¾, ½, ¾; 1, 1, ¾, ½, ¾, &c.[6] There is also a great difference in the intensity of

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[6] A more simple series could be had by a combination of eight half-size lenses and four large ones, in which each of the later would be followed by two of the former, which would give for the intervals of time between the middle or the ends of the successive flashes the periodic series 1, 1, ½; 1, 1, ½, &c.: then mariners would not be compelled to observe so great a number of flashes in order to recognize the law of the period.

But there is another condition, which M. de Rossel and myself have thought would give to a flashing light a character still more easy to recognize: it consists in revolving around the central light sixteen half-size lenses, each embracing an angle of 45° in a vertical and 22.5° in a horizontal direction, while the truncated pyramid of small lenses, which forms a kind of roof over the lamp, would still be composed of eight lenses, the flashes of which would precede by 7° those of the eight corresponding half-size lenses with which they would be connected. Thus, upon two consecutive flashes, the first, composed of that from the additional lens and that of the half-lens, would be at least twice as long as the one that followed it, produced by a half-lens only, from which would result a succession of flashes alternately long and short. The system would possess still another advantage, the sum of the durations of the flashes would be nearly equal to that of the eclipses. The half-lenses would have less range than the entire ones, which embrace an angle of 45° both horizontally and vertically; but the intensity of the light would scarcely be reduced one-half, because the parts that are suppressed to the right and left of the axis in the full lens, in order to form the half-lens, will furnish less light than those that are left, which are nearer the axis; these half-lenses would give a light at least as brilliant as that of two thirty-inch parabolic reflectors. Thus, in sacrificing in this way a part of the intensity of the flashes to their duration, it is done in an economical manner, since in the total, a little light would be gained.

Instead of adding the flash of each additional lens to that of a half-lens, it could be inserted between the flashes of two consecutive half-lenses; it would then be distinguished by a difference of intensity which would be sufficiently pronounced to strike the eye, and there would be, besides, a great difference between the intervals of time that separate the centers of successive flashes, since there would result from this arrangement the very simple series 1, ½, ½; 1, ½, ½,&c. The particular effect of this flashing light would be to show very brilliant flashes the flashes, since six of them are almost twice as bright as the other four. But, the light of the weaker being still very intense, and this distinction only being recognized from memory, it appears from our experiments, that a lighthouse could not be distinguished by it in cases where the intensity of the lights was weakened by mist or fog, or by the great distance of the observer: because, at six leagues distance, and in the moonlight. Some attention is necessary to note the difference in the intensity of their flashes, though those of the half-lenses are still bright.

Large lenses have been employed with success by MM. Arago and Mathieu as signals in geodetic surveys, which were made toward the end of last autumn upon the coasts of France and England. One of these lenses, illuminated by a four-wick burner and placed at a distance of fifty English miles from the observer, was easily seen with a telescope an hour before sunset, and with the naked eye an hour after. It then appeared as bright as the fixed light of an English lighthouse off in nearly the same direction, and only fifteen miles away—that is to say, about one-third the distance. This example suffices to give an idea of the range and power of the large lens apparatus.

Not only will they be useful for the illumination of lighthouses, but they will doubtless be of use in the advancement of science. They furnish a powerful instrument, by which we can submit to the most intense heat, in the interior of a glass shell, bodies that we may wish to melt or volatilize, keeping them from the air or putting them in contact with another gas; many experiments, which could neither be made with the ordinary nor with Neuman's blow-pipe, will easily be made in this manner. May we not, at some future time, owe to these burning-glasses discoveries as surprising as those with which the voltaic pile has enriched chemistry?

If they render important service to scientists, and above all to mariners we will be indebted to the enlightened zeal with which M. Becquey always welcomes useful inventions and hastens the perfecting of them. The encouragement that he gave to M. Soleil was not confined

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succeeding each other at equal intervals, but between which, and in pairs only, will be inserted flashes much less brilliant.

to ordering the apparatus; the establishment of the necessary machinery for their manufacture required the advancement of considerable funds. M. the General des Ponts et Chaussees came to the assistance of the manufacturer, and by paying a certain amount in advance, encouraged him in the new undertaking, to which he devoted all his energies, assuring its success from the outset.

I ought to add that the zeal with which M. de Rossel supported the proposal for introducing the new system of lighthouse illumination, as soon as he saw the effect of our first lens, as well as the advice and encouragement that he gave us while the work was in progress, has contributed in a large measure to hasten the completion of the lenticular apparatus now finished.

The first one, the lenses of which were made of small pieces, and the outer surfaces segments of spheres, was tried last year before M. the Director General des Ponts et Chaussees and the members of the Commission of Lights, who were very well satisfied with the intensity of the light.

The second one, composed of eight large and eight small lenses, is to be submitted to a series of similar but more complete experiments, in which will be employed the mechanical lamp with clockwork movement designed to illuminate the lighthouse of Cordouan.

From a preliminary experiment made at Montmélian, situated 16400 toises[7] from the Arc de Triomphe of the Barrier de l'Etoile, upon which an apparatus was placed, it appears that the duration of the light (under favorable conditions) is one-half the duration of the eclipses; that a sensible diminution of the light, which occurs at the junction of the flash of the large lens with that of the small one, (but without absolute eclipse,) is perceived during one-fifth the total time of its visibility; and finally, that both flashes, especially the one from the large lens, are very fine at that distance.

[7] A toise is equal to 6.56 feet.

Postscript

Since reading this memoir, I have thought of a means of prolonging the duration of the flashes, without changing the arrangement of the large and small lenses, by the addition of an apparatus which will not interfere with the service of the lamp, and will leave the table on which it rests entirely free. It consists of a system of small silvered mirrors, fixed below the large lenses and between the uprights which sustain them, and arranged like the slats of a Venetian blind; instead, however, of being parallel, each set should have the proper inclination, to reflect the rays parallel to each other, and each bunch of rays corresponding to a large lens should make an angle of 14 or 15 degrees with the axis of that lens, placed in advance of the direction of motion, so that the flashes produced by this system of small mirrors will precede the flashes of the additional lenses by the same angular distance that the latter precede the flashes of the large lenses. I think we can thus succeed at small expense, and without adding more than 200 pounds to the weight of the apparatus, in giving to the flashes a duration nearly equal to that of the eclipses. Finally, I propose to soon make a trial of this addition to the apparatus, and to verify by experiment these approximate theoretical results.

Appareil Lenticulaire pour l'Éclairage des Phares.

Coupe Verticale

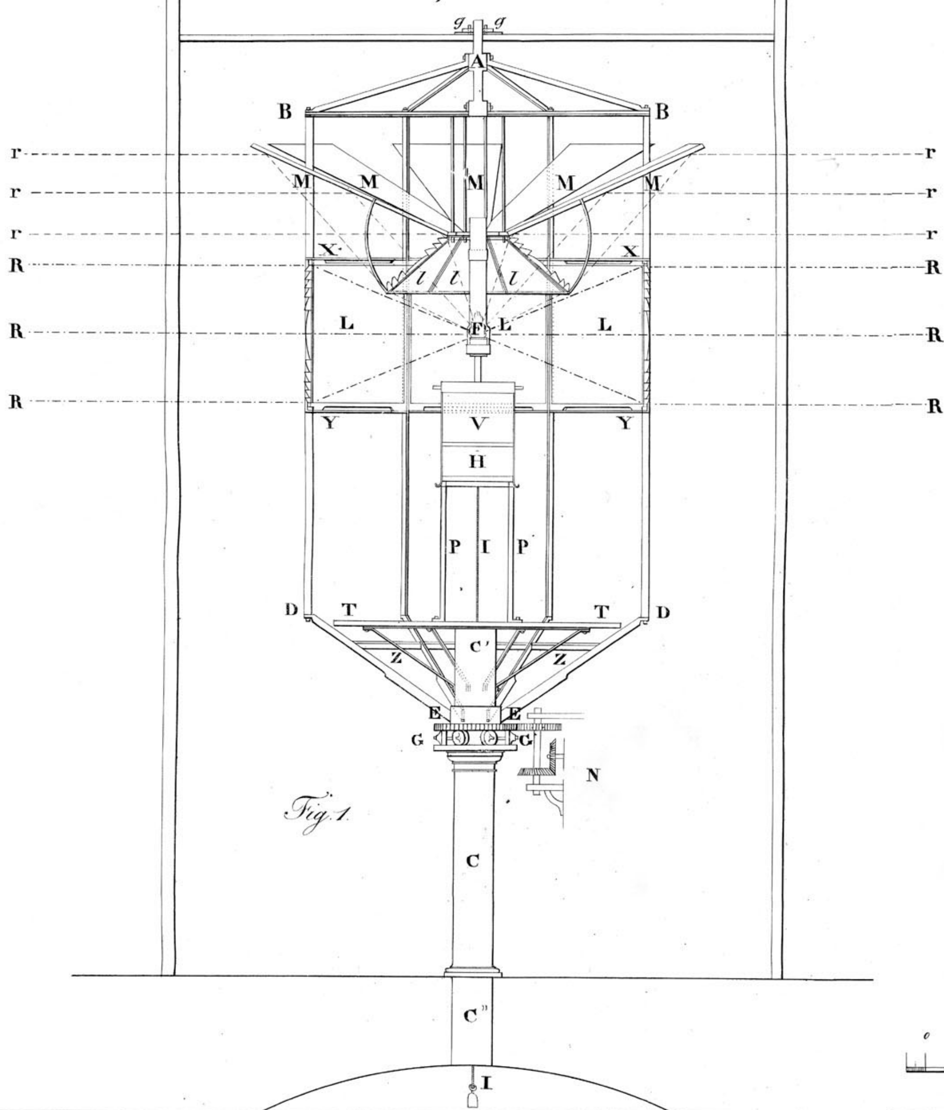


Fig. 1.

Projection Horizontale

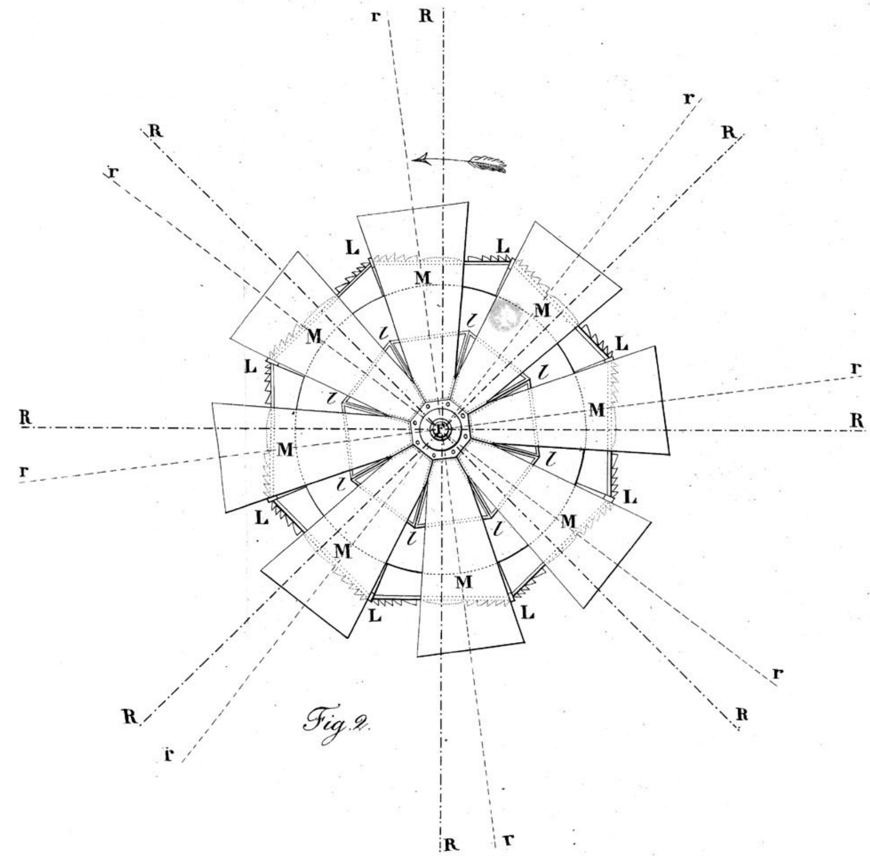


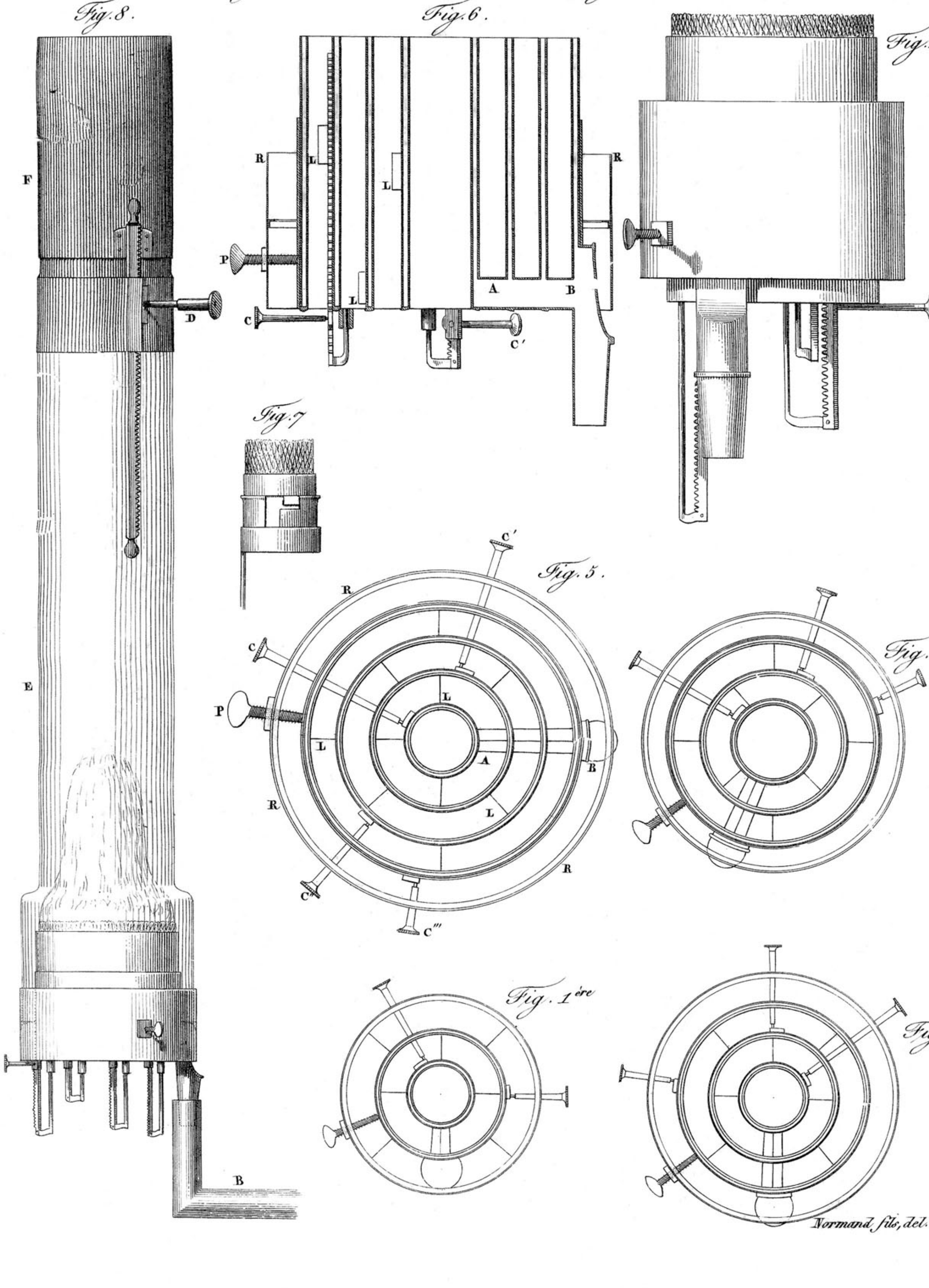
Fig. 2.

Échelle de quatre centimètres pour Mètre

Saunier, Lith.

Imp. Lith. de Lacroix

Lampe à double courant d'air et à plusieurs becs concentriques pour l'éclairage des Phares, de M.M.rs Arago et Fresnel.



Normand fils, del. et sc.