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"Nec aranearum sane textus ideo melior quia ex se fila gignunt, nec noster vilior quia ex alienis libamus ut apes." JUST. LIPS. *Polit.* lib. i. cap. 1. Not.

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JANUARY 1859.

I. *On the Camera Obscura.* *By* Prof. Petzval *of Vienna**.

On the 23rd of July, 1857, Prof. Petzval presented his new object-glass to the Academy of Vienna, and at the same time made a communication on the general properties of the camera obscura, which, from its elementary character, is well adapted to supply photographers with much accurate and valuable information. A somewhat complete abstract of this communication, therefore, cannot fail to interest a large number of readers.

A camera obscura may be defined as an instrument for obtaining, at a finite distance, an image of any number of objects; and in accordance with this definition, numerous properties at once suggest themselves as desirable. It will be well, in the first place, to enumerate the properties which may be reasonably demanded, in order subsequently to examine how far such demands can be satisfied.

We may reasonably demand that the image shall be well defined or sharp, that it shall also be well illuminated so as to exhibit proper light and shade; further, that it shall be true to nature, and also that it shall lie in a plane. If possible, too, the camera should simultaneously furnish images of both near and distant objects, should possess a large field of view, and give at pleasure either large or small pictures. Lastly, the instrument must have a convenient form, and cost as little as possible.

Most of these desiderata exist in an arrangement wherein the optician's art is quite dispensable. If a screen be placed

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* For the report, of which an abstract is here given, see *Sitzungsberichte der mathem. naturw. Classe der kaiserlichen Academie der Wissenschaften,* vol. xxvi. p. 33.

behind a small hole in the shutter of a carefully darkened room, an inverted image of external objects is at once obtained which possesses, in great perfection, many of the desired properties. We have here absolute faithfulness to nature; pictures at once of near and of distant objects, a field of vision as near to 180° as we please, and either a plane or a curved image. The expense of such an apparatus is small enough, and its convenience indisputable: in short, the picture obtained fails only in sharpness and illumination, but it must be admitted that these defects are so serious as to render the arrangement next to worthless for most purposes. Nevertheless, for many reasons, the arrangement in question deserves closer examination: it furnishes an excellent example of what nature presents, and of what art must supply; we learn from it also how often natural endowments are sacrificed when, by artificial means, we seek to enhance the nobler properties of sharpness and illumination; and lastly, we may here study the nature and influence of the imperfections inseparable from this the *natural camera*.

Let us assume that the external object is so distant, that every point of the same sends to the hole in the shutter a cone of rays so acute as not to differ essentially from a cylinder. If light were propagated in straight lines, it is manifest that the rays of every such cylinder would reach the screen in full possession of their own peculiar colour and intensity of light, and that they would impart both these qualities to a small portion of that screen, nearly circular in form, and of the same size as the hole. The several coloured spots thus formed would group themselves so as to constitute an inverted picture of the object, and the sharpness of this picture would be capable of being augmented indefinitely by diminishing the size of the hole.

Light, however, instead of being propagated in straight lines, is turned aside or diffracted on passing through an aperture, and thus gives rise to far different phænomena. The external object being a luminous point, a star for instance, its image is not only always greater than the hole, but on diminishing the size of the latter we find that, as soon as a certain limit has been reached, the image, instead of diminishing accordingly, actually becomes larger and less luminous. On closer examination this image is found to consist of a round luminous spot surrounded by concentric rings, alternately light and dark. The central spot is always found to possess the greatest intensity of light, the surrounding light rings being in general so faint as only to be perceptible by artificial means.

Since in everything which concerns the telescope, the microscope, or the camera, it is of the utmost importance to study the nature and magnitude of the defects caused in the picture by the diffraction of light, it will be useful to enter into further details. We may suppose the defect in sharpness to be measured by the diameter of the above circular spot, conceived to extend up to the commencement of the first dark ring. To obtain this diameter, let a right line be drawn from the centre of the hole to the screen so as to be perpendicular to the plane of the shutter. Upon this line, from the centre of the hole, set off a portion equal to the diameter of the latter. From the extremity of the line thus set off conceive another line to be drawn at right angles whose length λ is equal to that of a wave of light, *i. e.* $\frac{1}{50,000}$ in. or $\frac{1}{100,000}$ in., according as the light is red or violet. If, lastly, a line be drawn through the centre of the hole and the extremity of the last perpendicular, it will, on being produced to the screen, determine a point in the circumference of the circle, whose centre is in the line first drawn, and whose diameter, D, is required. If ρ be the radius of the hole, and A its distance from the screen, we have already

$$2\rho : \mathrm{A} = \lambda : \frac{\mathrm{D}}{2}, \text{ or } \mathrm{D} = \frac{\mathrm{A}\lambda}{\rho}. \quad . \quad . \quad . \quad . \quad (1)$$

This formula is only an approximate one, applicable when ρ is very small; in the case of a larger aperture, its diameter must be added to the value above given, that is to say,

$$\mathrm{D} = 2\rho + \frac{\mathrm{A}\lambda}{\rho}.$$

From the last formula we can at once deduce the best value for ρ; in other words, the size of the aperture which corresponds to the least possible value of D, and therefore to the sharpest possible image. In fact, differentiating the last expression, and setting, in the ordinary manner, $\frac{d\mathrm{D}}{d\rho} = 0$, we find at once

$$\rho = \sqrt{\tfrac{1}{2}\mathrm{A}\lambda}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

which corresponds to

$$\mathrm{D} = 2\sqrt{2\mathrm{A}\lambda}.$$

For instance, if $\mathrm{A} = 11$ in., then for red and violet light we have respectively

$$\rho = 0{\cdot}010 \text{ in.}, \quad \rho = 0{\cdot}007 \text{ in.},$$
$$\mathrm{D} = 0{\cdot}042 \text{ in.}, \quad \mathrm{D} = 0{\cdot}030 \text{ in.};$$

whence we learn that, on the whole, it would be useless to diminish the diameter of the aperture beyond $\frac{1}{60}$th of an inch, and that, under the most advantageous circumstances, the image of a luminous point is a circular spot $\frac{1}{24}$th of an inch in diameter. The picture we should obtain under these circumstances would clearly bear no magnifying whatever, but, on the contrary, would require to be inspected at a distance of 12 feet at least; for it is at this distance that a line $\frac{1}{24}$th of an inch in length subtends an angle of 1 minute, and it is only when objects are seen at this visual angle that they appear to be mere points. To obtain a more correct estimate, however, of the sharpness and illumination of the picture in the natural camera, let us compare it with that of a camera with a tolerably good object-glass of 3-inch aperture and 11-inch focal length. In the middle of the field the picture furnished by such a camera—there are of course far better instruments—will bear magnifying at least ten times, or, if we may use the expression, will bear inspection at a distance of $\frac{4}{5}$ths of an inch, and consequently, in point of sharpness, is $144 \div \frac{4}{5} = 180$ times superior to the picture in the natural camera. With respect to illumination, it will be observed that the two cameras have the same focal length, 11 inches, and consequently furnish equal-sized images of all external objects; their apertures, however, have the ratio 1 : 180; that of the first being $\frac{1}{60}$th of an inch, whilst that of the second is 3 inches. Now the focal length being constant, the illumination of a picture increases in proportion to the square of the aperture, so that with respect to this property, the camera with, is 32,400 times superior to that without glass. It is necessary to observe, however, that a picture so well illuminated as the one here used as a term of comparison, could in practice be scarcely obtained.

Two things are worthy of notice in the foregoing. In the first place we see how, by artificial means, that is to say, by means of well-arranged and properly curved lenses, it is possible to increase the qualities of sharpness and illumination in an instrument,—the first in the ratio of 1 : 180, and the second, indeed, in the ratio of 1 : 32,400. In the second place, we have become acquainted with a kind of aberration which puts a limit to the extreme use of diaphragms before camera lenses. To illustrate this still more, let us suppose that, in order to improve the properties of the picture, we were to try the experiment of reducing, by an interposed diaphragm, the aperture of the lens from 3 inches to $\frac{1}{2}$ an inch. It is evident from the formula (1), where $\lambda = \frac{1}{50,000}$ in., $A = 11$ in., and $\rho = \frac{1}{4}$ in., that we should thereby cause the image of a luminous point to become a round spot nearly $\frac{1}{1200}$th of an inch in diameter. Now in fine engravings, &c. we often meet with lines whose breadth is even less than $\frac{1}{600}$th of an inch; so that if our blinded lens were employed to copy such engravings, these fine lines would appear still finer in the picture, in consequence of the overlapping of the aberration circles of the adjacent luminous points. This defect would also be increased by the aberrations due to other causes, such as the curvature of the image, &c., so that ultimately the fine black lines of the original would in the copy be either undistinguishable, or at most mere pale shadows; at all events the picture, if it bore examination with the naked eye, would suffer no magnifying.

In order to advance step by step, let us now return to the natural camera, and seek to improve it by introducing into the hole in the shutter a small, simple, and therefore unachromatic lens of crown glass, which, for the sake of comparison, we will suppose to have a focal length of 11 inches. Let us examine what good properties are lost and gained by this certainly cheap alteration.

As long as the aperture of the lens is small in comparison with its focal length, we may safely assume that, apart from diffraction, the equally refrangible rays in any incident cylinder are made to converge to a point,—in other words, that on placing the screen properly, the image of a point in homogeneous light is itself a point. This condition of placing the screen exactly in the focus of the lens at once constitutes an inconvenience, inseparable from the new camera, which did not exist in the natural one. There are, however, graver complications to notice. Glass does not refract all rays of the spectrum alike; each differently coloured ray has a different focus, and the screen cannot of course accommodate all. To examine the consequences here involved, let n be the index of refraction for red rays, and p the distance of the corresponding focus from the centre of the lens, whose anterior and posterior surfaces we will suppose to have the radii r and r' respectively; then by a well-known formula,

$$\frac{1}{p}=(n-1)\left(\frac{1}{r}-\frac{1}{r'}\right); \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and $n+dn$ being the index of refraction for violet rays, whilst $p+dp$ is the corresponding focal distance, we have on differentiating (3),

$$-\frac{dp}{p^2}=\left(\frac{1}{r}-\frac{1}{r'}\right)dn=\frac{dn}{(n-1)p}$$

whence

$$dp=\frac{pdn}{1-n}.$$

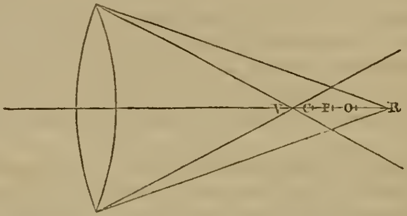
For crown glass,

$$\frac{dn}{n-1}=0{\cdot}036,$$

consequently

$$dp=-0{\cdot}036\,.\,p, \text{ or } dp=-0{\cdot}396 \text{ in.} \quad . \quad . \quad (4)$$

since by hypothesis $p=11$ in.; that is to say, for the most refrangible violet rays the focal length is less than that corresponding to red rays by $\frac{2}{5}$ in. nearly. If the latter combine in a point R, the former will converge to a point V nearer the lens, and the foci of all the other rays of the spectrum will lie between R and V. The rays which, on account of their number or colour, exercise the strongest action on the retina, will be congregated about a determinate point O. Strictly speaking, the *optical focus* here referred to is not a fixed point, since all eyes are not affected in the same manner by differently-coloured rays, nevertheless it is in the neighbourhood of O that most observers obtain the best image. In another fixed point C, nearer to V than to R, will be collected the rays which exert the greatest chemical action; and at this *chemical focus*, which may also vary a little with the material exposed to the action of light, the best photographic image will be obtained. Lastly, about midway between V and R, there is a third point P at which the screen intersects the cone of rays in its narrowest part, the diameter of the circular section being



$$D=\frac{\rho \cdot dp}{p}=0{\cdot}036\,\rho,$$

where, as before, ρ is the semi-aperture of the lens, p its focal length for red rays, and dp the so-called linear chromatic aberration*.

To this diameter of the circle of chromatic aberration must be added that of the circle of aberration due to diffraction, with which we are already acquainted, so that the total aberration will amount to

$$D=0{\cdot}036\,\rho+\frac{p\lambda}{\rho}.$$

If we seek, as before, the value of ρ which corresponds to a mi-

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* The above formula expresses an important theorem in the theory of the camera as well as in that of the telescope, inasmuch as it shows that the diameter of the smallest circle of chromatic aberration is dependent solely upon the aperture of the lens, and not upon its focal length.

nimum of D, we readily find

$$\rho=\sqrt{\frac{p\lambda}{0\cdot036}}, \text{ and } \mathrm{D}=0\cdot072\sqrt{\frac{p\lambda}{0\cdot036}};$$

consequently for red and violet light we have, respectively,

$$\rho=0\cdot08 \text{ in.}, \quad \rho=0\cdot06 \text{ in.},$$
$$\mathrm{D}=0\cdot006 \text{ in.}, \mathrm{D}=0\cdot004 \text{ in.}$$

Thus the aperture which here corresponds to the sharpest image is about $\frac{1}{8}$th of an inch, or a little more than seven times the best aperture in the natural camera. Consequently the illumination of the image is increased in the ratio of 1 : 50 nearly, though it still remains inferior to the ordinary camera in the ratio of 1 : 648. At the same time, however, the sharpness of the image has been considerably improved. In the natural camera the image of a point had a mean diameter of 0·04 of an inch; it is now diminished to 0·005. The sharpness of the image therefore is now eight times greater than before, and in this respect is only inferior to the ordinary camera in the ratio of 1 : $22\frac{1}{2}$.

These not very important improvements in sharpness and illumination have been dearly enough purchased; for although the general faithfulness to nature has not been essentially impaired, the difficulty of obtaining sharp images has been increased, on account of the chemical and optical foci being now separated by about a quarter of an inch. It is true that the difficulty here alluded to might easily be overcome if the linear chromatic aberration, dp of formula (4), and with it the distance between the foci, were always the same; for then it would suffice to place the plate destined to receive the picture a quarter of an inch in advance of the ground-glass plate. But it must not be forgotten that the formulæ (3) and (4) are true only when the incident rays are parallel, in other words, when the objects are at a great distance. An object at a finite distance a from the lens gives an image, not at the focal distance p, but at a distance α from the lens, a, p, and α being connected by the well-known formula

$$\frac{1}{\alpha}=\frac{1}{p}-\frac{1}{a}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If we differentiate this expression according to the index of refraction, implicitly contained in p, we have

$$d\alpha=\frac{\alpha^2 dp}{p^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where $d\alpha$ represents the real linear chromatic aberration, which differs from the dp of formula (4) the more, the greater the difference between α and p, or the nearer the object. To take an extreme case, by way of example, let $a=2p$, that is to say, let the distance of the object be reduced to double the focal length, then by (5) $\alpha=2p$, and by (6) $d\alpha=4dp$; so that the linear chromatic aberration is now quadrupled, and, as a consequence, the distance between the separated foci is increased to an inch. This varying distance between the chemical foci constituting, as it does, so serious a defect inseparable from all cameras with unachromatic lenses, the best possible achromatism is even more indispensable for this instrument than it is for the telescope itself.

The formula (5) also informs us of another disadvantage of the new camera as compared with the natural one. In the latter, the fact of the objects being at different distances was of no importance; in the former, however, the images of near objects are more distant from the lens than are those of more remote objects; and since the plane of the screen cannot accommodate all, it follows that if some images are sharp, others cannot be so. This inconvenience compels the photographer to have recourse to many expedients (such as grouping of the objects, &c.), of which some will be considered in the sequel.

Again, the sharpest parts of the picture of a distant plane object no longer fall in a plane, but on a spherical surface whose radius is $\frac{3}{2}p=16\frac{1}{2}$ in., and whose concavity is turned towards the lens. In consequence of this unavoidable circumstance, and the many difficulties attendant upon photographing on curved surfaces, sharpness must be sacrificed the more the field of view is increased.

Above all other things, however, the restoration of achromatism is the most important; for the chromatic aberration disappearing thereby, aperture and consequently illumination may be increased, whilst at the same time the aberration arising from diffraction will be proportionally diminished. As is well known, this achromatism is obtained by a combination of crown- and flint-glass lenses; and the method which has long been employed in telescopes not only leads to achromatism, but also diminishes a new defect known as spherical aberration. The latter manifests itself the more the greater the aperture, and is caused by the spherical form given to the surfaces of the lenses,—a form which, although most easily constructed, is not the one best adapted for causing all the rays of a pencil to converge to the same point. In ordinary telescopes the construction of the object-lens is rarely based upon strict calculations as to the best curvatures for obtaining the desired effects, the latter being determined generally by trials. The crown-glass lens is biconvex, the flint-glass one plano-concave; and the two are placed together so as to form a plano-convex system. When employed, the convex side is turned towards the object, the plane one towards the image, and the instrument fulfils its purposes more or less perfectly according as the curvatures of the constituent lenses have been more or less happily chosen.

In Daguerre's time these telescopic object-glasses, transferred to the camera, were in general use. In all probability, too, they were at first placed in the same manner, with the convex side towards the object; but experiment must soon have shown that this disposition was not applicable. For, destined by their construction to give very sharp but very small images, spherical aberration is destroyed only near the axis of such lenses,—in consequence of which, when the field of view is larger, a great deterioration in sharpness is observed on passing from the centre towards the edges of the picture. This deterioration is increased, too, by the fact that the image, instead of being plane, as required by the camera, lies on a curved surface which approaches in form to that of a paraboloid of rotation, whose radius of curvature at the vertex is equal to $\frac{3}{2}$ of the focal length p.

In the absence of calculations founded on theory, by means of which the sharpness at the edges of the image might be increased, opticians have sought to improve the telescopic lens, so as to adapt it to the camera, by diminishing its superfluous sharpness at the centre, or rather by rendering the contrast between the centre and the edges less striking. To obtain a notion of how this may be accomplished, let the object-lens of a good telescope be unscrewed and turned so as to present its plane side to the object. By so doing, the good telescope will be converted into a very poor instrument; and in order to obtain even a tolerable image, extreme blinding of the lens must be resorted to. The reason of this is to be sought in the serious spherical aberration that has been called into existence; the rays belonging to one and the same cylinder no longer converge towards a single point, but by their successive intersections give rise to a luminous curve or caustic, whose path intersects all the planes drawn perpendicular to the axis in the vicinity of the focus, by which latter term is now meant the point to which rays parallel to, and *very near* the axis, converge. The advantage of a diaphragm before the lens is, that it can be placed so as to admit only those rays of a cylinder whose intersections correspond to that part of the caustic which is situated in the plane of the picture. In order to convert a telescopic lens into a tolerably good camera lens, the cylinder of rays which corresponds to an image near the edge of the field must be treated in the manner described, and the position of the diaphragm determined accordingly. With a lens 3 inches in aperture and a focal length of 16 inches, such as was in general use in the early period of daguerreotyping, the diaphragm is best placed at a distance of 3 inches before the lens, its aperture being 1 inch. The image thus obtained, although tolerably good, will not be of uniform sharpness; in the centre it will perhaps bear magnifying three times, whilst at the edges it will barely admit of examination with the naked eye. In point of sharpness, therefore, this picture is at least three times inferior to the one of the camera already used as a term of comparison. With respect to illumination, the superiority of the ordinary modern camera is still greater; for since the degrees of illumination are directly proportional to the squares of the apertures, and inversely proportional to the squares of the focal lengths, the ratio in question is

$$1^2 \times 11^2 : 3^2 \times 16^2 = 121 : 2304 \text{ or } 1 : 19 \text{ nearly.}$$

It must be noted, however, that the modern camera has four more reflecting surfaces than the old one, by which means almost one-fifth of the light is lost, and the above ratio diminished to about 1 : 16.

The substitution of an achromatic in place of an unachromatic object-glass is, beyond comparison, the most important step in the improvement of the camera; for not only have the properties of sharpness and illumination been thereby increased—the former in the ratio of 1 : 7, and the latter even in the ratio of 1 : 40,—but the serious defect of separated optical and chemical foci has been remedied. Besides this, the image has become nearly plane—a result which, it is true, might also have been obtained in the case of an unachromatic lens by means of the same method of blinding. Lastly, the field has become almost uniformly lighted; the not very broad zone of diminishing intensity of light which still exists is due to the blinding. As diaphragms often produce this defect, it will be well to examine their action more closely.

Around the centre of the lens, and with a radius of 1 inch, conceive a circle to be described: its circumference will be at the distance of half an inch from that of the lens. The diaphragm, at the distance of 3 inches, having an aperture of 1 inch, all cylinders of rays passing through the same will be entirely received by the lens, provided their axes are within or upon the circumference of the above circle, and the corresponding images will possess the maximum intensity of light. The rays of every cylinder whose axis meets the lens in the circumference of the circle are inclined to the axis of the instrument at an angle whose tangent equals $\frac{1}{3}$, and whose magnitude is therefore 18°; consequently everywhere within a field of 36° the image possesses full intensity of light. Again, only half the rays of those cylinders whose axes exactly graze the edge of the lens will be admitted by the latter, the entrance of the rest being prevented by the setting. These rays are inclined at an angle of 26° to the axis of the instrument, so that between 36° and 52° the intensity of light in the field will diminish from its maximum value to one-half of the same. Lastly, the lens will admit none of the rays of the cylinders whose axes meet its plane at a distance of half an inch from its edge; consequently, between 52° and 66° the intensity of light diminishes from half its normal value down to zero. Thus when uniform light is required, the field must not exceed 36°; in other words, the focal length being 16 inches, the diameter of the circular picture cannot exceed 10 inches.

Such are the properties of the instrument with which Daguerre worked when he made his beautiful discovery. At that time silver plates, coated with iodine, were alone employed; and the time of exposure required was so great—half an hour—that portrait-taking was next to impossible. Hence arose the demand for a camera lens producing greater illumination, and equal or, if possible, greater sharpness. Sooner or later practical opticians would, no doubt, have sought to improve the camera of Daguerre by substituting a convex-concave, in place of the plano-convex achromatic lens; for the former, treated in the manner above described, possesses several advantages. Science, however, stepped in with more efficient means, and Prof. Petzval, after a thorough theoretical investigation of the subject, set about constructing his first object-glass, destined principally for portrait-taking.

In so doing he was guided by the following considerations:—The object-lens of a telescope has only three conditions to fulfil: *first,* to possess a given focal length; *second,* to be achromatic; and *third,* to reduce the spherical aberration to a minimum. The first is a matter of small importance, for within certain limits the focal length may vary; the achromatism depends on the focal lengths of the constituent lenses, and the spherical aberration on the curvatures of their surfaces. The three conditions, therefore, can be fulfilled by suitably disposing of three optical elements, *i. e.* the curvatures of three surfaces.

In the camera, however, the number of these conditions is raised from three to eight, five of which have reference to a much more complete destruction of spherical aberration, two to the production of achromatism, and the eighth to the position of the focus. Instead of three, therefore, eight optical elements are requisite, the choice of which will be determined by the following considerations. Greater illumination, one of the desired improvements, can only be obtained in two ways—by enlarging the aperture and by diminishing the focal length, both which, however, will result from employing two converging lenses instead of one. These lenses must of course be achromatic; and by theory, in order that a good image may be produced, they must be separated from each other by a distance not less than one-third of the focal length of the lens next the object. In order to form the eight requisite elements, therefore, seven lens surfaces and one distance may be selected. By this selection the first lens need but present three surfaces to be disposed of, so that its constituents may have a common surface; the second lens, however, in order to furnish the remaining four surfaces, must have its constituents separated, even though by so doing light is lost.

In accordance with these data, Prof. Petzval calculated, and Voigtlander constructed, a new object-lens which had an aperture of 1½ inch, and a focal length of 5½ inches. With it portraits were taken in forty seconds; in point of illumination it was sixteen times superior to the camera of Daguerre, and its images were sharp enough to bear magnifying twenty times. The principal defects of the new camera were a curved image and limited field of view, both of which resulted from the employment of separated lenses.

With respect to the first defect, the image of a plane object was, according to theory, situated in the hollow of a paraboloid of rotation, having at its vertex a radius of curvature equal to 7 or 8 inches. In object-glasses afterwards constructed, where the aperture was increased to 3 inches, this curvature was softened to 15 inches. By sacrificing a little sharpness at the edges, too, circumstances generally furnished means of softening this curvature still more. For portraits, indeed, a camera capable of giving a plane image of a plane object would be no acquisition, inasmuch as the persons whose portraits are to be taken by no means constitute such plane objects. With a single individual, or with a group of such, the skilful photographer may always arrange the position of his subjects so that the image will fall nearly in a plane.

The second action of the separated lenses deserves closer examination. It will be at once seen that here the setting of the first lens plays the part of the former diaphragm, and modifies the admission of light to the second lens. As an example, let us take an object-glass whose two lenses are 5⅓ inches apart, the aperture of each being 3 inches. Let the focal length of the first lens be 16 inches, and that of the second 24 inches. Then by means of the first lens, a cylinder of rays parallel to the axis becomes converted into a cone, whose vertex is 16 inches behind this lens; and the plane of the second lens intercepts this cone in a circle whose diameter is diminished to 2 inches; the same is true approximately for every other cylinder inclined to the axis of the instrument. Around the centre of the second lens, therefore, let us conceive a circle of $\frac{1}{2}$ inch radius described; its circumference will be at a distance of 1 inch from that of the lens, and it is clear that the second lens will admit all the rays of every cylinder whose inclination to the axis of the instrument is such, that the axial ray of that cylinder, after passing unrefracted through the first lens, meets the second in the circumference of the above circle. The image produced by such a cylinder, therefore, will possess the same maximum of illumination as do the central images. But the entrance of the rays of other cylinders more inclined to the axis of the instrument will be more or less impeded; and by following the method already explained in the case of Daguerre's camera, it will be found that throughout a field of $10\frac{2}{3}^{\circ}$ there will be maximum light; that between this and a field of 32° the intensity of light will diminish to half its normal value; and lastly, that the whole extent of the field, beyond which is darkness, amounts to about 50°. These angles correspond on the picture to circles whose diameters are 2, 6, and 10 inches respectively.

When portraits only are to be taken, that is to say, when a correct picture of only a small portion of the object is desired, this unequal distribution of light is of no great importance. In the case of landscapes, however, it forms a serious defect, and necessitates the use of diaphragms, not only to distribute the light more uniformly, but also to diminish the influence of the unequal distances of objects, and to soften the curvature of the image. The best place for the diaphragm is exactly midway between the two lenses, and by diminishing the intensity of light to $\frac{1}{4}$th, $\frac{1}{9}$th or to $\frac{1}{16}$th of its full value, the field of equal illumination may be increased to 31°, whilst the two zones, wherein the light first diminishes to half its normal value and then to zero, may be made much narrower. On finding that the picture thus obtained was superior to that of a camera with a simple achromatic lens, the instrument, which was constructed for portraits, was employed also for landscapes; and larger pictures being desired, the original object-glass of $1\frac{1}{2}$ inch aperture was reproduced on a larger scale, the aperture being increased to 3, 4 and even 5 inches in order to obtain pictures of 14 inches diameter. Practical opticians undertook this increase in size on their own responsibility; and the necessity of applying certain corrections to the curvatures was not attended to; the consequence of which was, that the later productions of the camera were in every respect incomplete, and deteriorated by spherical aberration, double foci, and other imperfections. These efforts to increase the size of the original instrument being in other respects unpromising, the demand arose for a new object-glass, which, without supplanting the old one, but rather restricting the same to the use for which it was intended, should be suited to the reproduction of landscapes, maps, engravings, &c.

The modifications applied to the old instrument to fit it for its new purposes, had for their object, principally, to increase the magnitude of the field and the uniformity of its illumination, and consisted in a diminution of the distance between the two lenses, and of the aperture of the second. The object-glass, constructed carefully with a view of fulfilling all the new conditions, and submitted to the Academy of Vienna, consists, as before, of two lenses; the first has an aperture of 3 inches and the second of of 2 inches, the clear distance between the two being 1 inch. The magnitude of the picture is the same as that corresponding to a single achromatic lens of 26 inches focal length, its diameter being 20 inches; in other words, the field amounts to 42° and is uniformly lighted. This last result is due to the diminished aperture of the second lens, and has been purchased, of course, at the expense of intensity of light. The curvature of the image of a plane object is small, its radius at the vertex being about 80 inches.

With respect to the achromatism of the two lenses, it is well known that the ratio between the indices of refraction for crown- and flint-glass is not constant, but varies with the colour of the ray, and that on this account the rays of all colours cannot be made to coincide, simultaneously, by any arrangement of the two kinds of glass; in other words, according to the technical expression, a certain chromatic aberration of the secondary spectrum always remains. In the telescope most attention is paid to the coincidence of the rays at the red end of the spectrum, and, without injury to the picture, a considerable aberration of the rays at the violet end may exist. These rays, however, exert the greatest chemical action, whence it happens that the object-lens of a telescope gives a less sharp photographic, than it does an optical image. On the other hand, if the opposite end of the spectrum were most attended to, the photographic picture would be improved at the expense of the optical one, and in both cases the chemical and optical foci would be separated. In constructing the new object-glass, the whole spectrum, rather than either end of the same, was regarded, and the most active chemical made to coincide, approximately, with the most active optical rays, so that, for a healthy eye, the chemical and optical foci coincide.

From the above exposition it follows that, whilst the new camera is inferior to the old in point of illumination, it far surpasses the latter in magnitude of the field, and in uniformity of sharpness as well as of illumination. Whilst the new camera, therefore, is best adapted for landscapes, the old one may still be used whenever a brief period of exposure is desirable, as in taking pictures of living animals*.

To suit the properties of the new object-glass, a new camera, greatly exceeding the ordinary ones in bulk, became necessary. M. Petzval submitted a design to the Academy, remarking at the same time that it was no doubt susceptible of improvement. Without entering into a detailed description of all the arrangements in this camera, it will suffice to note the principal objects aimed at. These were a diminution of the whole mass as much as possible, a division of the same into several convenient parts, avoidance of false light, an arrangement for inclining the plane of the image to the axis of the instrument, in order to accommodate the different distances of the objects, and lastly, an improved method of uncovering the iodized plate without shaking the instrument.

Whilst admitting that his attempt to attain these objects is susceptible of being improved upon, Prof. Petzval does not hesitate to pronounce his object-glass to be the best attainable with the given optical elements. In order to test its merits, he selects the most delicate of all photographic problems, that of obtaining, on a reduced scale, the copy of a map or engraving. He enters into interesting details as to the best method to be employed, the principal feature of which consists in first bending the plane of the map to be copied into a developable surface, so as to make it approach as much as possible to coincidence with the parabolic surface, which according to theory. corresponds to a plane image. As an example, he takes a map 24 inches by 16 inches, and places his instrument at a distance of 13 feet, in order to obtain a copy $\frac{1}{5}$th the size of the original. Every expedient being adopted, he calculates then that all lines in the original whose breadth exceeds $\frac{1}{240}$th of an inch will be transferred to the copy.

After some remarks on obtaining enlarged copies of pictures, and a few instructions for testing the merits of an object-glass, Prof. Petzval concludes his valuable report by stating that he has confided the construction of his new object-glasses to M. C. Dietzler.

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* The new camera has also the advantage of having a more invariable period of exposure, that of the old one depending greatly on the magnitude of the field. Approximately, however, these periods have the ratio of 3 : 1.