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1900 Trans. Opt. Soc. 2 21

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ON TELESCOPES AND FIELD GLASSES.

PAPER BY DR. D. KAEMPFER, BRUNSWICK.

IN the history of natural philosophy and science the invention of the telescope in the beginning of the 17th century was of the greatest importance. It must, however, be stated that the influence on the progress of science did not prove to be so great at first, although Galilei succeeded in discovering the satellites of the planet Jupiter by it. The renowned astronomer Hevelius even in 1650 could still deny with certain right the efficiency of the telescope in comparison with observations by sharp-sighted eyes. The reason why the telescope could not help failing was that no means were extant in those times to diminish the chromatic and spherical aberrations both in the objectives and in the eye-pieces; and no less an authority than Sir Isaac Newton, who at first taught the world by his wonderful experiments how to divide the white sunlight into its seven coloured parts, prevented makers of telescopes from trying to counteract these deviations, because he declared it to be impossible.

It was not until John Dollond in the year 1757, in London, combined in spite of this great authority, crown and flint glass to form the achromatic objectives, that this great progress came forth. Since that time a continual improvement of all the systems of telescopes, both of the Galilean and the Kepler types, with astronomical eyepieces and terrestrial ones has been made. Mathematical investigations and new methods of melting good optical homogeneous and suitable glasses, practical accomplishments of the art of polishing and centering the lenses, in order to execute the design in the most perfect manner cumulated with one another to bring this wonderful instrument—the telescope—to the highest pitch of perfection. Names like Lippershey, Galilei, Kepler, Dollond, Herschel, Lord Rosse, Fraunhofer, etc., will never be forgotten if we are to review the development of this branch of optics. From a historical point of view we are bound to remember these names even if we are to only give a short sketch of small telescopes for practical use, Galilean and prismatic binoculars, which are the subject of my lecture.

The oldest type of telescopes for free use in the hand is the Galilean opera-glass, constructed as binocular glasses at first by Frederick Voigtländer in Vienna, in the year 1811. They are composed of an achromatic double or triple objective with the ratio of aperture to length of focus of 1 : 3 up to 1 : 5, and a negative (single, double or triple) eyepiece, placed in its normal position at a distance equal to the difference of the focal lengths of the objective and eyepiece. The eyepiece being set in the course of the pencils of light piercing the objective, the images are not really produced, but are upright. Let us now contemplate only in the outlines the course of light in those glasses.

O is the objective, P the eyepiece, E the human eye, then the pencil of light piercing through O from the left side is converged by O , meets P , where its convergency is lessened, coming thus into the eye E . If we follow *vice versa* the rays from the pupil of the eye through the eyepiece P and the objective O , we are enabled to find the field of view

FIG. 1.

enclosed between the lines AC and BC ; those lines cutting each other in C give the angle of the field W . This shows evidently, that the field of view depends upon the size of the object-glasses, and is restrained by the impossibility to make them larger than $2\frac{1}{2}$ ins. approximately, the distance of the eyes being only $2\frac{1}{2}$ ins.

The Galilean glasses possess the advantage of being comparatively short, the distance of objective and eyepiece equalling the difference of the focal lengths of both. Furthermore, there are only a few lenses through which the light passes; therefore, absorption and false reflexion are reduced to a minimum. The image, therefore, is most brilliant, not covered by ghosts or weakened by absorption in thick lenses.

The illuminating power of the Galilean binocular cannot be excelled, it equals very nearly that of seeing with unaided eye, *i.e.*, the utmost to be attained, for an optical system is never able to increase the natural light. I have brought with me some specimens made by

Voigtländer and Sohn, glasses in all forms and mounts, from the magnifying power of $2\frac{1}{2}$ up to 7, in metal and aluminium, with triple achromatic objectives and eyepieces. You will be able to examine them afterwards. I should like to draw your attention to some special glasses, with six lenses, whose bars are absolutely united with the bodies, both in metal and in magnalium, the new and wonderful alloy of aluminium and magnesium, on which I shall make some remarks after having finished this subject. This mechanical design makes the glasses extraordinarily steady and prevents them from coming out of adjustment.

Here is a model of the German navy night glass, the German artillery glass, etc.; the artillery glass has the same optical outfit in a more compact mount.

If you hold these glasses up to the light, the eye being in some distance from the eyepiece, you will see an illuminated round circle of

FIG. 2.

more than $\frac{1}{3}$ of an inch in diameter; this circle is therefore larger than the pupil of the human eye, which altering according to the changing light, can become as much as $\frac{1}{3}$ inch in darkness. The pupil of the human eye determines the amount of light which reaches the retina.

Though the illuminating power is the greatest possible, the Galilean glasses possess disadvantages which makes them unsuitable for use in some cases. Above all, the magnifying power is comparatively low, from two to seven or eight diameters, as higher powers make the glasses very large and inconvenient to hold, and diminish the field of view enormously.

It is quite natural that Kepler's astronomical telescope, consisting of two positive systems of lenses, seemed to offer greater advantages in this direction, the eyepieces possessing a field of view of 40° . But

the images were inverted and upright images are required for terrestrial use. A rough sketch will show us this.

O is the achromatic objective, P the astronomical eyepiece; then an image of the object is really produced in B . You see from the course of rays that the image in B is upside down, and that the eyepiece does not erect it. Another essential difference between the astronomical and Galilean telescopes is that the image of the objective obtained by the eyepiece is produced in this case outside the telescope on the right side, as you can convince yourself if you hold such a telescope against the light. In the Galilean type, however, this illuminated circle, the so-called emerging pupil of the light, is seen between the objective and eyepiece. This circle, the emerging pupil or Ramsden's circle, has a great importance in the theory of telescopes of any kind and it may consequently be worth while to explain it in connection with the magnifying power.

FIG. 3.

Let us represent in our mind the telescope in its most simple shape. Fig. 3 shows the telescopic system in its normal position, objective (O) and eyepiece P are simple bi-convex lenses, their distance is the sum of the focal lengths f and f^1 the second focus of O falling together with the first focus of P in the point G .

Parallel light to the axis is converged in G the focus of O ; coming from G as the focus of P , the refractive power of P will make it parallel to the axis. This parallel pencil forms the Ramsden's circle, the emerging pupil, and as we are enabled to see here, it is the image of the objective O , formed by the eyepiece P . It can easily be seen, if we look on the eye-glass at a short distance, holding the telescope against direct light or an illuminated white sheet of paper. The Ramsden's circle gives us all that is necessary to judge the illuminat-

ing power of a telescope, the larger its diameter the greater is the light and *vice versa*.

But it will tell us more than that if we look at the sketch, fig. 4, in order to obtain a geometrical view of the magnifying power.

The object glass O produces a real image $A'B'$ of the distant object AB , which is smaller (inverted), and is situated at the distance of its focal length f . The eye seeing $A'B'$ through the eyepiece P will bring it apparently into the position CD , the distance between P and $A'B'$ being f' , the focal length of B . The angle, under which the object AB is seen is a , the angle under which the image CD is seen is β ; the ratio β/a is the magnifying power. Contemplating the triangles OBG' and PBG' we conclude, supposing the tangents of small angles equal the angles themselves, that the magnifying power β/a equals the ratio f/f' of the focal lengths of the objective and the eyepiece. The

FIG. 4.

angle β is called the apparent field of view of the eyepiece, hence the real field of view equals the ratio β divided by the magnifying power. If we look at fig. 8 again we are allowed to conclude that the ratio f/f' equals the ratio

$$\frac{\text{diameter of objective}}{\text{diameter of Ramsden's circle}}$$

the triangles AGB and $A'GB'$ being similar to each other.

We have, therefore, won three very important theorems by which to judge the efficiency of telescopes. Firstly, the magnifying power equals the ratio of the focal lengths of objective and eyepieces. Secondly, the same equals the ratio of diameters of objective and Ramsden's circle. Both can be easily measured, and from these measurements the magnifying power can be derived. Accurate instruments are designed for this purpose, for instance, Ramsden's

dynamometer, but we have not time to refer to them now. In many cases it is sufficient to apply a mechanical measure. Thirdly, the real field of view equals

apparent field of view of the eyepiece.
the ratio : $\frac{\text{apparent field of view of the eyepiece.}}{\text{magnifying power.}}$

We may add that the Ramsden's circle also gives the illuminating power, so that we are enabled to judge all the geometrical properties of a telescope.

Naturally our theorem of the ratio of the diameters of objective and Ramsden's circle is only available, if the objective is not stopped down artificially, in order to improve the definition. We can see ourselves if this has been done by looking at some distance through the objective of the telescope ; if the whole aperture is illuminated, the telescope is not stopped down.

FIG. 5.

The astronomical telescope gives the picture inverted which peculiarity excludes it from practical use for terrestrial purposes. In order to make the image upright we are obliged to bring between objective and eyepiece a reversing system, as shown in fig. 5. $B'A'$ is the reversed picture of an object, designed by an objective ; then the pencils of light coming from A' and B' piercing the lens 1 cross the axis in U , going through 2 and 3, they form in $A''B''$ the upright image, which is observed by the eyeglass as a magnifier. It can be easily shown that the lens 3 determines the field of view, as a collective lens.

You see here some of the standard forms of terrestrial telescopes, now in use, manufactured by Messrs. Voigtländer and Sohn, for their English and American friends, as well as for the German navy, the German army preferring binoculars. One, with an aperture of $1\frac{3}{4}$ ins., magnifying power 18 ; the other with an aperture of $2\frac{3}{4}$ ins., power 26 ; they are the standard patterns of the German navy.

English gentlemen mostly prefer for military as well as for sporting purposes, deer-stalking, etc., draw telescopes, both in aluminium and in brass with the same optical outfit, as they are more portable.

The advantage of the terrestrial eyepiece is balanced by many disadvantages, chiefly the great length and deficient flatness of field. So it is nearly impossible to build up satisfactory binoculars of this design, being too long and heavy for practical use. The astronomical eyepiece in all these respects is by far superior; all the good efficiency being spoilt by the employment of the reversing system in the terrestrial telescope. But there is still another means to reverse the image in an astronomical telescope, that is Porro's combination of two equilateral and rectangular prisms. This useful construction has been invented by the Italian mathematician and engineer, Porro, as early as in 1853, and it was not until in 1869 that earnest trials were made to introduce it into practice.

In these models I have represented the combination of Porro-prisms. The white wire represents the axis of the objective and of the parallel pencil of light piercing it; it meets perpendicularly the hypotenuse of the right angle equilateral prism, without suffering refraction or reflection at that surface. Then it hits the first side at an angle of 45° , thus total reflection must take place, the reflected ray going parallel to the hypotenuse meets under the same angle the second side, where it is again reflected totally and then emerges perpendicularly from the hypotenuse. This course of the ray is marked on the outside of the prism. The ray emerging from the first prism meets the other prism, whose refracting edge is set perpendicular to that of the first prism, perpendicularly on its hypotenuse, undergoes in the same way two total reflections on its catheti, whereupon it emerges from the second prism in a direction perpendicularly to its hypotenuse thus represented by the red wires.

A refractive effect is nowhere produced, only four reflections take place, the pencil of light coming from the objective emerges in the same direction, only displaced in a parallel line. The inverted image given by the objectives becomes upright by these four reflections, but where does it come from? To form the right idea of these phenomena we compare the effect of the first two reflections with a right-angle mirror. In such a mirror right and left side, or up and down, are always inverted, according to the position of the edge. If the edge is perpendicular on the horizon of the observer, then right and left are changed: if the edge is horizontal, top and bottom are changed. Con-

sequently a complete reversion of an image, right and left, and top and bottom, is only provided by two perpendicularly crossed right-angled mirrors or what signifies the same, by two right-angle equilateral totally reflecting prisms, crossing each other rectangularly.

You can convince yourself of this fact by experiments with such two prisms, as I can show you here. Take the one, hold it, the edge being perpendicular, on the ground; right and left are changed; hold it, the edge horizontal; top and bottom are changed. Both of them combined with parallel edges give no inversion at all, the two efforts paralysing each other, the inversion will not be realised till the two prisms are crossed and you see how the image is turned over if you move the one prism into the crossed position, looking constantly in the meanwhile through the other prism.

From our models it is evident that the direction of the pencil of rays is displaced. This can be used in binocular glasses for enlarging the distance between the objectives. This property has been used for obtaining a higher stereoscopical effect, similar to the telestereoscope invented by Helmholtz about 40 years ago. But the stereoscopical effect can also be produced and in smaller instruments to a greater extent by using higher magnifying power. But another property of this combination is of a by far greater practical use. It is that the Porro combination shortens the telescope a good deal, the course of the rays being composed of three tracks going beside each other, of which two can be subtracted from the length of the telescope, and of two tracks parallel to the hypotenuses and perpendicular to the axis, which possess no influence at all on the length of the instrument. These two principal advantages of the Porro combination over the terrestrial reversing system, that it does not spoil the wonderful efficiency of the astronomical eyepiece and shortens the length of the telescope so much, are of the highest importance for binocular glasses, for in this line shortness and compactness are of the greatest importance. Let me tell you some words about the historical development of these instruments in our firm. You will see here a monocular telescope with a combination of Porro prisms for reversing the image and an astronomical eyepiece. It was constructed in 1869 as a telescope for the Austrian cavalry, but was set aside afterwards on account of its deficient illuminating power. Later on it was discovered that this construction possessed the faculty to fill up a gap between the Galilean binocular glasses and the telescopes with ter-

restrial eyepieces only for use in the free hand. We designed and brought out prismatic binoculars with single adjustment for the eyes and with simultaneous adjustment for both eyes. The latter are almost invariably preferred.

You see here the ordinary patterns of prismatic binocular glasses, magnifying powers 3, 6, 8, 9, and 12 diameters; the optical effect is the best attainable, the Ramsden's circle being between 4, 2 and 1,8 mm., the illuminating power is quite sufficient for the use during the day, when the pupil of the human eye only possesses the same diameters. The image is sharply cut, achromatism and flatness of field are perfect. The apparent field of view lies between 36 and 42 degrees, the real field of view between 3, 5, and 10 degrees. You will overlook 105 yards in a distance of 1,000 yards by means of a binocular of six times, 61 yards with one of 12 times. Beyond 12 times it is not of a practical use to raise the power, though the task for the Optician is no more difficult than with 12 times. The objective is double achromatic, the prisms of the purest, brightest glass material, so that the loss by absorption can be nearly considered as imperceptible, the eyepiece is a so-called Ramsden one, the collective glass turning its plane surface to the objective, the eye-glass is double-achromatic.

There are two more samples of a special line of binocular-glasses, one with the magnification $\times 3$ has an enormous field of view, overlooking 200 yards in a distance of 1,000 yards, although it is built up in a much reduced compass. The converging pupil being 4 mm., the luminosity is comparatively great, consequently the glasses are most useful in the theatre, when it is desired to overlook at one time the whole scene. The other glasses, magnifying $\times 4$ possess the highest luminosity of all prismatic binoculars, the converging pupil having a diameter of 7 mm., they will naturally be applied with the greatest success at dawn, in weak light, etc.

I may be allowed to mention something about the optical and mechanical workmanship and portions. In the ordinary prismatic binocular glasses we do not only employ the simultaneous adjustment for both eyes by an ordinary propelling screw, but also use an appliance for one eye to compensate the frequent difference of efficiency of the two eyes. I have brought with me such a single eyepiece, to show the mechanical movement. Bodies, and nearly all other metal parts, are cast out of the firmest alloy of aluminium, formerly aluminium-copper, now aluminium-magnesium or magnalium, the

newest, lightest and steadiest of all these alloys. This cast body will show you how the prisms are set and fastened, etc.

I should like to point out that a good design only is not sufficient to build up a good instrument for the use by free hands, but that the best workmanship is indispensable for manufacturing these glasses, both in the optical and in the mechanical parts. Particularly the prismatic binoculars offer manifold difficulties in accomplishing them so steadily, that they are enabled to stand against any injury and keep up their adjustments. How Messrs. Voigtländer and Sohn have overcome this difficulty, these patterns will show, and the experience that dropping on the ground, knocking on the bodies, etc., hardly ever spoils them. Prisms must be of the highest performance, as well as the objectives and eyepieces, the least want of perfection will make an adjustment impossible. A similar theorem is available for Galilean glasses and hand-telescopes, although deficiency in the workmanship with those glasses will not be of so great influence on the adjustment itself. But the effect is spoiled in this case as well as in the case of the prismatic binocular, if the workmanship and finish are neglected. Perfect centering of the single tubes and of the lenses in them, parallelising of the binoculars, absolutely spherical and highly polished surfaces are necessary in every case, so that a great deal of labour, pains and cleverness always remain for the conscientious manufacturer.

I may be allowed to conclude my explanations with a summary on the choice of glasses for the use in the hand. Three cases are to be considered. If the highest luminosity is required, that which enables us to make full use of the natural property of the human pupil when very widely enlarged in dim or weak light, Galilean opera or field-glasses are to be employed, for instance, in the theatre, if one will not only see the illuminated scene but also the dark parts, or on board of a ship during the night to find the marks on sea or ships, etc.

If on the contrary the highest magnifying power is desired, a hand telescope, magnifying fifteen to thirty-six diameters, and luminosity does not signify much, only terrestrial telescopes are to be chosen with an emerging pencil of 2 mm. as an average. It will be sufficient in day-time, for then the human pupil will have a similar diameter. These telescopes therefore will be of the greatest use on board a ship at day time, and when deer-stalking, hunting, etc.

If, however, a medium performance in both respects, both in luminosity and in power are asked for, prismatic binocular glasses will

come into question, standing in the most important qualities between the Galilean and terrestrial types of telescopes. They are the right instruments for universal use, although naturally they cannot give the utmost advantages in every direction.

In order not to omit anything belonging to the subject of my lecture, I should like to bring before you another interesting instrument, which is also used by hand. It is the aiming or sighting telescope. This is an extraordinarily short terrestrial telescope, serving instead of the mechanical sight on a rifle but avoiding its great faults. Taking aim signifies that four points, the object, the two parts of the sight and the eye, are to be brought into one straight line. But if you accommodate your eye on the object, you can never see the sight sharply and *vice versa*, hence the faults in aiming. In the sighting telescope the image of the object falls together with the cross wire of the telescope, consequently no fault of accommodation can occur, the aiming is absolute. Naturally the telescope must be fixed and adjusted in a practical and reasonable way, as Messrs. Holland and Holland and other firms do here in London. In Germany all the great sportsmen possess such rifle telescopes, following the example of the Emperor. Perhaps it may be of interest to you to see this rifle with the telescope on it, and have the details explained afterwards. It is naturally of very great assistance for sharp-shooting with the rifle. For the different distances the mounting of the telescope is managed in a way to allow the cross wire to be elevated according to the distances. For this purpose it is shot at a target and the corresponding heights of elevation marked.