we now discover that it too appears to wander, and that there are other Poles besides the one we were taught to regard as such. He directed attention to the distance which separates Alpha of Draco, which was the Pole Star 2,700 years before Christ, from our present Pole Star; and to the still greater space which separates the latter from Vega, the star which will be near our celestial North Pole in the year 13600 A.D. Our Pole Star will, however, retain its present position for 1,587 years, or till 3500 A.D. After defining the terms "Procession" and "Nutation," the President observed these were phenomena which in his opinion were often confounded. The two were no doubt connected, but they were by no means identical phenomena. The President also by a diagram on the black-board showed the distinction between the Celestial Pole, the Pole of the Ecliptic and the Galactic Pole. He then asked the meeting to return a hearty vote of thanks to Mr. Hart for the thought-provoking Note they had just heard and for the neatly executed diagram which accompanied it, and which Mr. Raman had kindly reproduced as the lantern slide which had been projected on the screen. (*Lantern slides shown by Mr. Tomkins.*)

President.—We must accord a vote of thanks to Kodaikanal for the very fine specimens of photography illustrating Solar Physics which we have just seen.

The meeting was then adjourned.

The Construction of a Cheap Telescope.

BY

H. G. TOMKINS, C.I.E., F.R.A.S.

PAPER IV.

WE left our mirror last month fairly polished and ready to be tested by a more accurate and sensitive method than hitherto adopted.

We have reached a stage at which the irregularities of the surface, if they exist, fail to result in any difference in appearance of the surface which may be detected by the unaided eye, and we have now therefore to resort to other means by which they may be detected. The two methods of testing which I propose to describe depend on much the same principles, and as it will be necessary for our workman to understand them before he can put them into practice, I shall in this paper describe the theory of the tests leaving the practical application until next month.

The test consists of observing the various reflections of light from an artificial star at the centre of curvature of the mirror. The artificial star is simply made by piercing a small hole in a tin chimney fixed to an ordinary oil lamp.

Let us first consider the testing of a spherical mirror, for it is this figure which we have first to aim at in order to obtain a parabolic mirror for the purpose of our telescope.

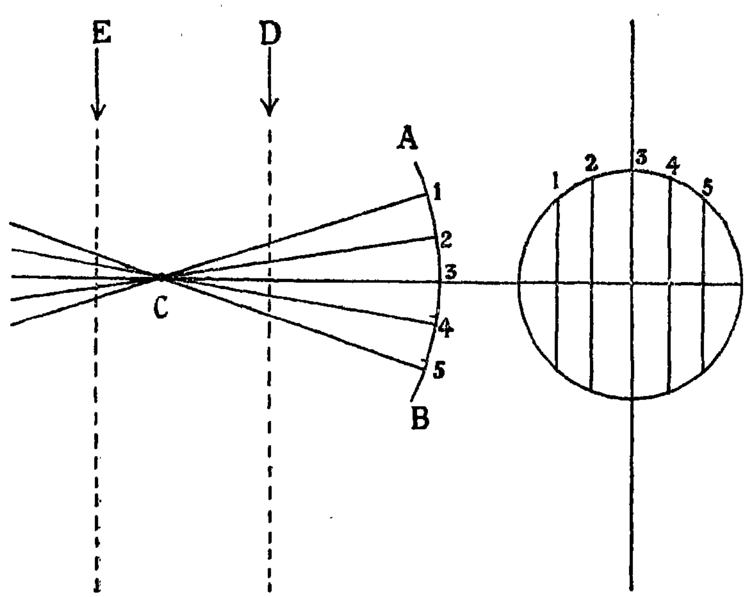

FIG. 8.

Suppose A B to be the spherical mirror, and the artificial star to be shining on it from the point C which is the centre of curvature of the mirror (distance equal to twice the focal length). Then if the mirror is perfect and if the star is exactly at C, it is obvious that the light will all be reflected back to C again. If now we move the star a little to one side (to the right is usual) and if we then place our eye near C, we shall receive the reflected rays from the mirror in our eye and we shall see the whole surface of the mirror illuminated. Those who have never actually seen it will be surprised to find how bright this illumination is. As we do not need to consider the paths of the light rays on the journey from the star *to* the mirror, I have omitted them from Fig. 8 to save confusion. Now suppose we pass a screen just in front of the eye between it and the mirror from left to right *at the point C* cutting the reflected rays, the result will be that the whole of the light from the mirror will be cut off from reaching the eye. That is to say, the mirror will darken equally all over. It will not darken first at one side and then the other, but equally from both sides. This will be evident from the fact that all the rays (I have drawn 5, numbered 1 to 5, in Fig. 8) meet at the point C where the screen is to cut them. Suppose now we put our eye a little closer to the mirror and again bring the screen before it as before—say at D. Now the rays will be cut off in order 1, 2, 3, 4, 5; that is to say, the face of the mirror will darken from left to right. At 3 the shadow will be exactly half across. Again, suppose we go further away from the mirror and bring the screen across at E. It is now evident that the rays will be cut off in the order 5, 4, 3, 2, 1; that is, the shadow will come on the mirror from left to right.

From these phenomena, it is evident that we can obtain a ready means of finding the centre of curvature of the mirror. If the shadow comes on the mirror from the left, when the screen is passed across from left to right, we know the screen is too close to the mirror; if from the right, it is too far away; if equally from both sides, it is at the centre of curvature. And the same rule will obviously apply if instead of applying the test to the whole mirror we cover up a portion of it and test any particular ring or zone. For instance, if we cover up the centre of the mirror with a paper disc 6 inches in diameter, we can then find the centre of curvature of an outside ring or zone one inch wide all round. By taking such zones in succession from the outside edge of the mirror to the centre by means of suitable discs, we can test the whole mirror zone by zone; and if we find the centres of curvatures of each of these zones are all situated at exactly the same distance from the mirror, it is evident that the figure of the mirror is spherical. Now let us examine the case of a mirror with a bad figure: let us take a hyperbola as in Fig. 9.

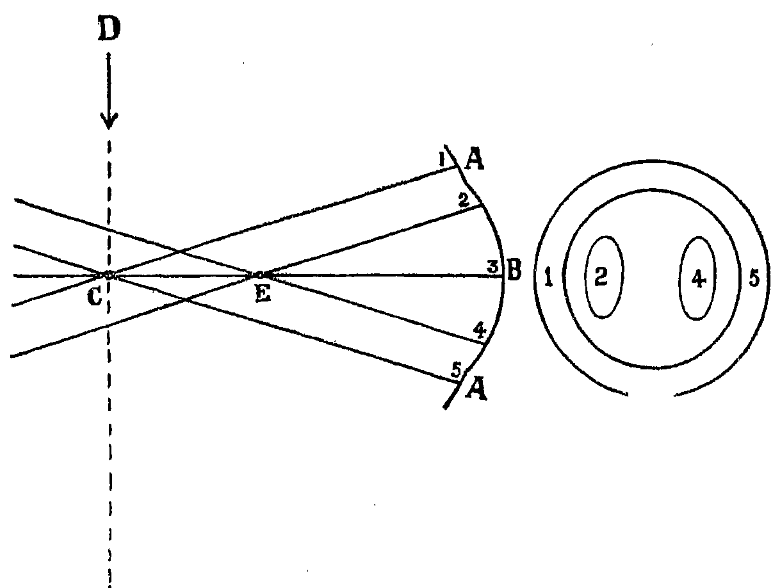

FIG. 9.

Here we have the mirror too deep in the centre at B. The ring AA is not so deep. Let us now get the centre of curvature of the outside ring AA as usual by the method I have already described, and then from this point C examine the rest of the surface of the mirror. It is evident that the first ray cut off by the screen D will be 4, that is we shall have a black patch on the mirror at 4. I have also marked this in the plan of the mirror. Next we shall cut the point C producing shade at 1 and 5, that is on the outside ring. The patch 4 will also have extended to cover the mirror up to 3 and there will be left light only the patch at 2. This will also disappear when the screen reaches that ray. So that we see that a bad mirror has a very irregular way of shading, and the first shadow appears on the right, showing that the radius curvature of that part is too short: in other words the mirror is too deep.

Now let us take the opposite figure, namely an oblate spheroid. Here the centre is too shallow as in Fig. 10.

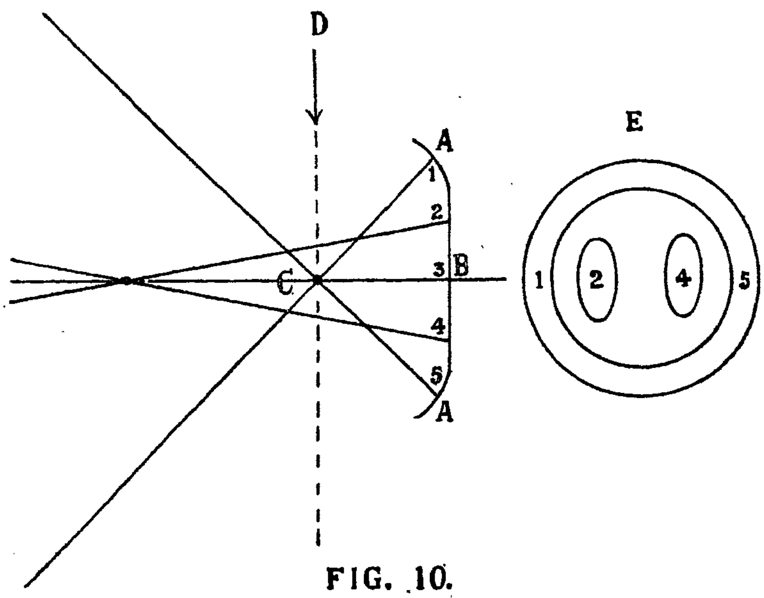

FIG. 10.

Again put the screen at the centre of the outside zone AA as before. This will be at C. In this case the first ray to be cut by the screen at D will be 2 : then 1 and 5 : then 4. That is to say, the dark patch will appear first at 2, then the ring at 1 and 5 will darken, and lastly the spot 4. This is the reverse of Fig. 9 as we should from the mirror expect it to be.

From the above it is obvious that we can find out by these means whether the figure of the mirror is a sphere, a hyperbola or an oblate spheroid, which is what we have been aiming at from the beginning.

The above is the test by means of examination of the whole surface of the mirror from the centre of curvature of the outside zone. But there is also another and even finer test which it is usual to apply. I have referred above to the method of finding the centre of curvature of the zones of the mirror separately by using suitable discs to cover the portions of the mirror not actually under test, and I showed that the centres of the successive zones in the case of a spherical mirror would be at the same point. Taking the zones separately we should in the case of a bad figure not find this. For instance, in the case of Fig. 9, the zone 1 and 5 would have its centre at C, while 2 and 4 would be at E. And as the centre in this case is *inside* that of 1 and 5, it is evident that the zone 2 and 4 is too deep: that is to say, we have a hyperbolic figure. In the same way the reverse will be the case with Fig. 10.

And by arranging a scale so that we can measure the relative distances of C and E from the mirror, we can tell exactly how much the centre of curvature of one zone differs from another, so that we by this means get an idea of *how much* too deep or too shallow the faulty zone of our mirror is. Hence we can regulate our future polishing operations.

Now, the figure we are trying to get for our mirror is not spherical but parabolic, because this is the form of mirror which will reflect to a focus the parallel rays of light from the heavenly object we view with the telescope. The parabola is a figure slightly deeper than the sphere, but not so deep as the hyperbola. The difficulty, therefore, is to deepen the sphere sufficiently, but not so much as to make it hyperbolic. It is evident that something in the shape of exact measurement is wanted, and fortunately the zone test above described lends itself readily to this by means of the scale I have mentioned. For it is clear that we only need to calculate the *correct* position for the centres of curvature of the various zones, and then to compare the actual positions with them to be able to bring our mirror to a perfect figure. It is not, of course, necessary to calculate and measure the exact distances of these centres *from the mirror*: it will be sufficient to take the outside or any zone as a unit (the outside one is usually taken in practice) and measure the others from it. I will not burden our members with a long mathematical calculation, but will simply give the formula by which the relative distances can be obtained. Those who wish to see the mathematical proof will find it in the monthly notices of the Royal Astronomical Society and also in the *English Mechanic* for 1895. The formula is $\frac{\left(\frac{d}{2}\right)^2}{R}$ where d is the diameter of the middle of each zone and R is the radius of curvature of the mirror (twice the focal length). From this it is easy to calculate the distances for any mirror. I have now explained the theory of these tests. In practice it is usual to apply them together, and I shall show how this can be done in my next paper.