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LIGHT WAVES IN ASTRONOMY[1]

WHEN any object is viewed in a telescope the image formed at the focus results from the concurrence of the light waves which reach the focus from all parts of the object glass.

In the simplest case—that of a star which is so far away that it may be regarded as a point of light the image will not be a point, but a disc of appreciable size surrounded by a series of concentric circles as shown in Figure 1*a*.

In the case of a double star each component will present such a figure readily separable in a telescope of adequate size as in Figure 1*b*.

But if the stars form a very close double, the two figures overlap as in Figure 1*c* and in this case the system is not to be distinguished as a double.[2]

It can readily be shown that the limit of resolution is reached when the relation between the angular separative α_0 is given when this is equal to the ratio of the length λ of the light wave to the diameter d of the objective multiplied by the constant factor 1.22.

Thus in case of the 100-inch telescope at Mt. Wilson the angle would be $1.22 \times 1/50000$ x 1/100 or one in four million, corresponding to an angle of about one twentieth of a second of arc; which may be visualized as the appearance of a dime thirty miles away.

Next consider the appearance of an object presenting an actual disc such as a small planetoid. Each point of the disc would form an image like that in Figure 1*a*, the integrated effect corresponding to the appearance in Figure 1*d*.

Here again the appearance of d will not be distinguishable from Figure 1*a* if the angular diameter of the disc is less than $\alpha_0 = 1.22\lambda/d$. This then corresponds to the utmost attainable

1 Abstract of a lecture given under the auspices of the Carnegie Institution of Washington on April 26, 1923.

2 At least not accurately measurable though there may be indications of doubling.

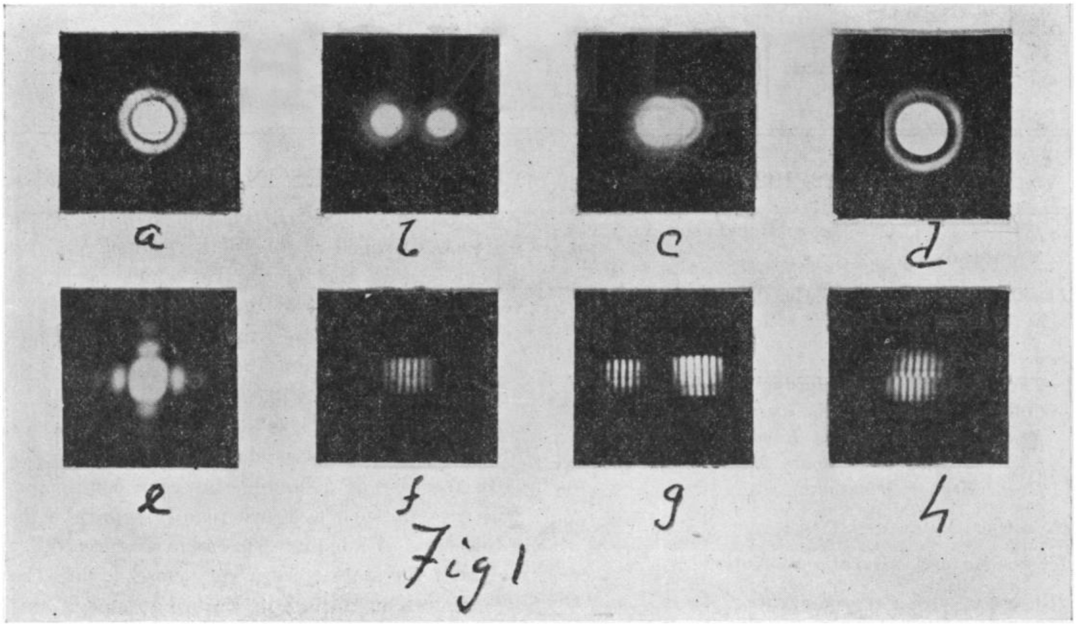


Fig 1

limit of resolution with the largest telescope in the world under perfect conditions of atmosphere.

But the character of the image at the focus (taking for simplicity the case of a star) depends on the form of the aperture of the telescope. If this were square instead of round the appearance would be that represented in Figure 1*e*.

If instead of a single aperture there are two arranged as in Figure 2 the appearance of the

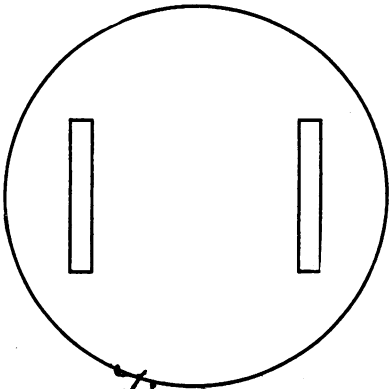


Fig. 2.

image of a star would be that shown in Figure 1*f*.

The figure presents no resemblance in this case to the object, but for purposes of measurement it has two important advantages. These may be best illustrated by considering once more the case of a double star, which would show a diffraction figure corresponding to Figure 1*g* if the two stars were well separated. If, however, the stars form a close doublet, these two figures will overlap[3] and at a definite distance will entirely vanish, if the two stars are equally bright. The graph representing the visibility of the fringes as a function of the distance between the two apertures is shown in Figure 3 corresponding to the formula

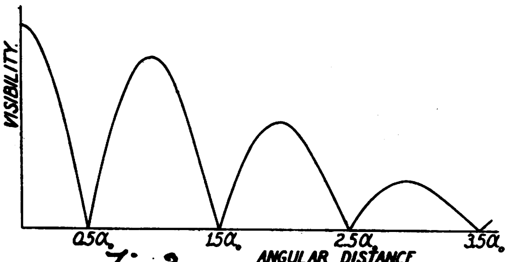


Fig. 3.

$V = A\cos\pi\alpha/\alpha_0$ ($\alpha_0 = \lambda/d$). The vanishing of the fringes (which may be observed with remarkable accuracy) occurs at intervals corres-

[3] Fig. 1h represents the diffraction figure due to a very close doublet, the components of which are not in the same horizontal plane. If they were in the same plane, the fringes would vanish.

ponding to $\alpha = 1/2\alpha_0$, $3/2\alpha_0$, etc., or when

$$\alpha = \frac{\lambda}{2d}, \frac{3\lambda}{2d}, \text{ etc.,}$$

so that the resolution of a doublet by this method can be clearly established with a telescope of only four tenths the diameter of that required when using the full aperture.

But much more important is the fact that the vanishing of the fringes (or even the observation of the minimum in case the stars are of unequal brightness) is capable of far greater accuracy than the more or less vague observation of "resolution." Similar considerations show that the curve, Figure 4, representing the graph of the formula

$$\gamma = \int_0^1 \sqrt{1 - w^2} \cos nw \, dw$$

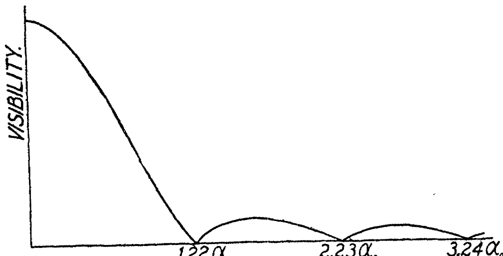


Fig. 4.

where $n = \pi d\alpha/\lambda$ give values $\alpha = 1.22\frac{\lambda}{d}$, $2.44\frac{\lambda}{d}$, etc., for the points at which the fringes vanish; whence α, the angular diameter of the disc, may be found—and with an order of accuracy but little inferior to that found in the measurement of the angular distance between the components of a double star.

A test, by the interference method, of the measurement of the diameter of the Satellites of Jupiter was made at Mt. Hamilton in 1890, giving results of considerably greater accuracy than any hitherto obtained, and proving clearly the applicability of the method to the measurement of discs of much smaller angular diameters than these. Thirty years afterward, by invitation of Dr. Geo. E. Hale, it was proposed to make an extended investigation into the possibilities of the method at the Mt. Wilson Observatory.

A preliminary trial with the forty-inch at the Yerkes Observatory showed clearly that interference fringes were readily observed even when atmospheric disturbances made "seeing" too poor for the usual astronomical observations. The same result[4] was obtained with the 60-inch and finally with the 100-inch at Mt. Wilson.[5]

The feasibility of the interference method being thoroughly confirmed, the problem of the investigation of the angular distance between the components of a double star was undertaken by Dr. J. A. Anderson.

From spectroscopic evidence Dr. W. W. Campbell showed that the star Capella was a binary star whose angular separation was just beyond the separating power of the 100-inch, so that it presented an object most suitable for the test.

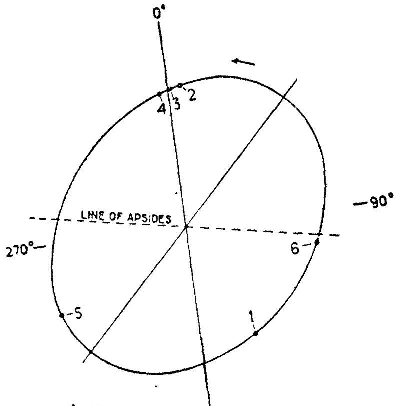


Fig 5.

The results of Dr. Anderson's work are shown in the graph, Figure 5, representing the orbit. The results of a comparison of the separate observations with the calculated orbit show that the accuracy of these measurements reach the extraordinary limit of one ten thousandth of a second of arc. (A dime at 30 miles distant would show corresponding irregularities of the

[4] In this last test a diaphragm with two small apertures was placed near the focus, instead of at the objective, making measurement much more conveniently and without any loss of accuracy.

[5] A probable explanation of this unexpected result is doubtless something like the following:

When the entire aperture of the telescope is used, the integrated effect of the atmospheric disturbances is a confusion of the focal image generally referred to as "boiling." In the case of two small apertures at opposite ends of a diameter, the fringe system moves as a whole, but is nevertheless quite distinct so long as the motion is not too rapid for the eye to follow.

order of a thousandth of an inch.) The stars are so far distant that, although many of them are much larger than our sun, the angular diameter of the disc they would present is too small for the largest telescope to discern. It would require a telescope two or three times as large as the 100-inch instrument at Mt. Wilson to render visible even the largest of these. The interferometer, however, offers a base line which may be much larger than the diameter of the telescope; and the previous work justified the hope that atmospheric disturbances would not seriously affect the clearness of the interference fringes.

There was, however, considerable doubt as to the possibility of constructing so huge an instrument with sufficient rigidity to prevent warping or vibrations the amount of which must not exceed a ten thousandth of an inch. The work was undertaken at the laboratory of the Mt. Wilson Observatory under the direction of Mr. F. G. Pease.

A preliminary test showed the interference fringes quite clearly, even with rather poor "seeing."

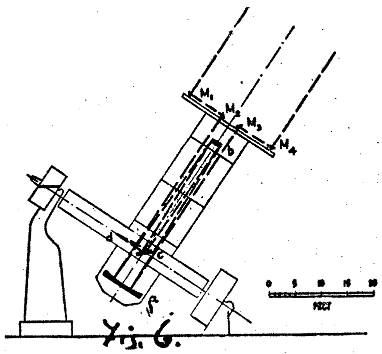
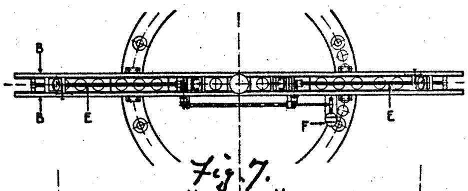
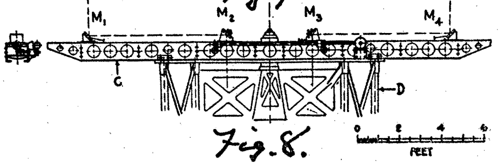


Fig. 6 gives a schematic view of the arrangement.





M, M_4 are two plane mirrors which reflect light from the star to the two mirrors M_2M_3, whence they proceed to the concave reflector M_5, proceeding thence ultimately to the focus of the instrument where they produce interference bands, which are viewed by an eyepiece at E.

Figure 7 shows the plan and Figure 8 the elevation of the interferometer beam and Figure 9 is a photograph of the beam attached to the tube of the telescope.[6]

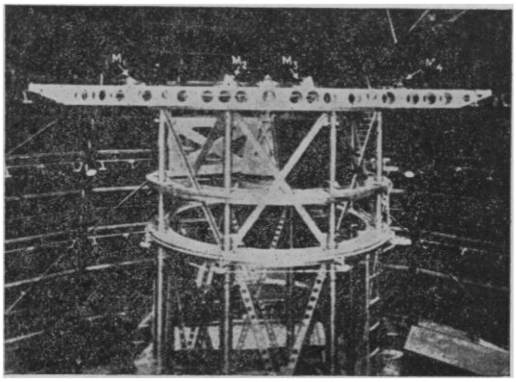


Figure 9

On December 13, 1920, Mr. Pease reported: "After preliminary settings on β Persei, with the mirrors separated 81 inches; and on β Persei and γ Orionis, with a separation of 121 inches (thus insuring that the instrument was in perfect adjustment), it was turned on α Orionis (Betelgeuse) and the interference fringes were sought for some time but could not be found. When next turned on α Canis Majoris the fringes at once appeared, thus furnishing a complete check."

The expression of the relation between α, the angular diameter of the star, and the distance δ between the mirrors at disappearance is $\alpha=1.22\lambda/d$. Assuming the effective wave length $\lambda = 5750$ Angstrom units, and $d = 300$ c.m. the anguar diameter of Betelgeuse is $0''.047$. To find the actual diameter of the star we must multiply this by the distance of the

6 It was not at all necessary for optical requirements to use so large a telescope; but the 100-inch had such great stability that the additional weight (some 800 pounds) produced no derangement of its adjustments.

star, which in terms of its parallax 0″.018 gives a result

$$\frac{.047}{.018} \times 92{,}500{,}000,$$

that is a diameter of 240 million miles, 300 times the diameter of our sun!

This value is based, however, on the assumption that the disc presents a uniform illumination; but as there is undoubtedly a falling off of intensity away from the center this result may be considerably too small.

Since the announcement of this result several other stars have shown an appreciable diameter and one, Antares, is found to be even a bigger giant than Betelgeuse.

A still larger interferometer with a base of fifty feet is now under construction, by means of which the number of stars which fall within range will be considerably increased and it may even be hoped that the distribution of light over the discs may be determined.

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TWENTY-SEVEN KINDS OF MEN

THERE are twenty-seven kinds of men. It is worth while to take account of personal stock and to honestly decide which of the twenty-seven varieties we ourselves represent, for it may be possible, within limits, to change ourselves, if desirable, into different sorts of men.

Or better yet, we might try to classify our neighbor whose faults, if not his virtues, are usually more apparent than our own. It is always an engaging mental exercise to size up other people since success in life depends largely upon correct judgments concerning those with whom we have to deal. In order to do this fairly we must discover what determines the sort of person our neighbor is and wherein he or she differs from twenty-six other kinds of people. There are three contributing factors that go to make up any man—or woman—and no one of the three can possibly be omitted.

The first is *environment* or the surroundings in which a person is brought up. It represents the opportunity or chance in life which one has. The second is *natural capacity* which is inherited from one's forbears. This is heredity or endowment. The third factor is the *response* which is made with a given inheritance, whatever it may be, within one's particular surroundings.

Environment is the stage setting; inheritance the actor and the response what the actor performs upon the stage. The play involves all three. Environment is what a man *has;* inheritance is what he *is* and response is what he *does.* It takes all three of these things to make a neighbor or any one else.

Furthermore, inheritance is decided beforehand for every man. No one can choose his parents or determine the inborn capacity with which they endow him. It is too late to do that when one arrives on the scene. If a man draws a blank in his biological inheritance he is simply out of luck for he cannot change it or draw again.

This is why there is no real reason for any one to be either proud or ashamed of his "blood," or his ancestry, whatever it may be. He has no hand in determining it. One may, however, properly feel pride or shame for the environment in which he remains or for the response that he makes with whatever ability he has to that environment, since both of these factors are to a degree within his control. When he marries he may also feel pride or shame in the mate whom he chooses to be the fellow determiner of the natural capacity which he wills to his children, because it is within his control thus to enrich or cheapen the blood that he has to pass on to the next generation.

To reduce the matter to the simplest terms, the three fateful factors that determine a man, namely, environment, heredity and response, may each occur in at least three varying grades indicated roughly as good, medium and poor. By combining these factors we arrive at twenty-seven kinds of men. For example, the inheritance that a man is born with may be good, medium or poor. Likewise the environment in which he finds himself and the response that he makes under the circumstances may be also good, medium or poor. In the list below are given the twenty-seven possible combinations resulting from this simple arrangement: