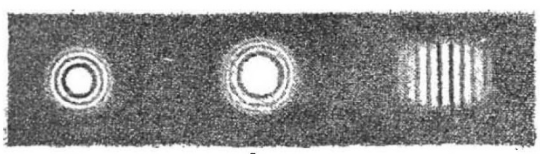
the elongation, the former, below Pole, later. In this way the right ascension of Polaris plays a small part in its azimuth of elongation, which is dependent solely on the declination and latitude. Assuming the present declinations of the two stars mentioned, with probable errors of $< \pm 0''\cdot2$ and $\pm 0''\cdot3$ respectively, he finds that the right ascension would probably be in error by $\pm$ 0·002s. and $\pm$ 0·004s. In fact, the probable errors "dependent upon anything but the transit of the star to be determined will be much less if the present method is used (with an equal instrument), than if stars in the same declination, but opposite Polaris in right ascension, were observed by direct comparisons in the meridian." By applying this method to other stars of different right ascensions and "gradually increasing declinations," as the R.A. of Polaris or its opposite is approached, numerous co-ordinates thoroughly independent can be obtained, and will "provide zero points for the proposed number of photographic plates 2° square, and consequently help to settle the places of all stars in that region."

MEASUREMENT OF JUPITER'S SATELLITES BY INTERFERENCE.

IT has long been known that even in a telescope which is theoretically perfect, the image of a luminous point is composed of a series of concentric circles with a bright patch of light at the common centre. This system of circles can easily be observed by examining any bright star with a telescope provided with a circular diaphragm which diminishes the effective aperture. The appearance of the image is shown in Fig. 1, *a*. In the case of an object of finite angular magnitude the image could be constructed by drawing a system of such rings about every point in the geometrical image. The result for a small disk (corresponding to the appearance of one of the satellites of Jupiter as seen with a 12-inch telescope whose effective aperture

Fig 1



a b c

has been reduced to six inches) is given in Fig. 1, *b*; the chief points of difference between this and Fig. 1, *a*, being the greater size of the bright central disk, and the lesser clearness of the surrounding rings. The larger the disk the more nearly will the appearance of the image correspond to that of the object; and the smaller the object the more nearly does it correspond with Fig. 1, *a*, and the more difficult will be the measurement of its actual size. Thus, in the case just cited, the actual angular diameter is about one second of arc, and the uncertainty may amount to half this value or even more.

The relative uncertainty, other things being equal, will be less in proportion to the increase in the aperture, so that with the 36-inch telescope the measurement of the diameters of Jupiter's satellites should be accurate to within ten per cent. under favourable conditions.

It is important to note that in all such measurements the image observed is a diffraction phenomenon—the rings being interference fringes, and the settings being made on the position of that part of a fringe which is most easily identified. But such measurements must vary with the atmospheric conditions and especially with the observer—for no two observers will agree upon the exact part of the fringe to be measured, and the uncertainties are exaggerated when the fringes are disturbed by atmospheric tremors.

If, now, it be possible to find a relation between the size of the object and the *clearness* of the interference fringes, an independent method of measuring such minute objects will be furnished; and it is the purpose of this paper to show that such a method is not only feasible, but in all probability gives results far more accurate than micrometric measurements of the image.

In a paper on the "Application of Interference Methods to Astronomical Measurements"[1] an arrangement was described for producing such fringes, by providing the cap of the objective with two parallel slits, adjustable in width and distance apart. If such a combination be focussed on a star, then, instead of the concentric rings before mentioned, there will be a series of straight equidistant bands whose length is parallel with the slits, the central one being brightest,[1] Fig. 1, *c*.

The general theory of these fringes may be found in the *Philosophical Magazine* for March 1891. The general equation showing the relation between the *visibility* of the fringes and the distance between the slits is

$$V^2 = \frac{\left[\int \phi(x) \cos kx\, dx\right]^2 + \left[\int \phi(x) \sin kx\, dx\right]^2}{\left[\int \phi\ (x)\ dx\right]^2} \quad . \quad (1)$$

which reduces to the simpler form

$$V = \frac{\int \phi\ (x) \cos kx\, dx}{\int \phi\ (x)\, dx} \quad . \ . \ . \ . \ . \ . \ . \ . \ (2)$$

when the object viewed is symmetrical.

A number of applications of this formula are discussed in the former paper, but for the present purpose attention will be confined to the case in which the object viewed (or rather its projection) is a circular disk, uniformly illuminated.

In this case equation (2) becomes

$$V = \int_0^1 \sqrt{1 - \omega^2} \,.\, \cos \pi \frac{\alpha}{\alpha_0} \omega \,.\, d\omega \quad . \ . \ . \ . \ . \ (3)$$

in which α is the angular diameter of the object, and α_0 is the smallest angle resolvable by an equivalent aperture; that is, the ratio of a light-wave to the distance between the slits.

The curve expressing this relation is given in Fig. 2, in which the ordinates are values of the visibility of the fringes, and the abscissæ are the corresponding values of the α/α_0.

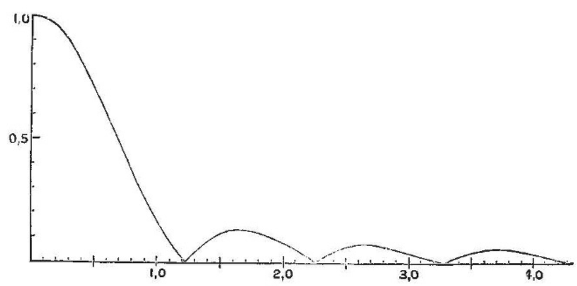


FIG. 2.

From this it will appear that the fringes disappear at recurring intervals, and in a laboratory experiment as many as four such disappearances were noted, and the average error in the resulting value of α, the angular magnitude of the disk, was found to be less than two per cent.

From the curve it is evident that the first disappearance is most readily and accurately observed, and for this we have

$$\frac{\alpha}{\alpha_0} = 1\cdot22\,;$$

whence, putting s for the distance between the centres of the slits, and taking for the wave-length of the brightest part of the spectrum 0·0005 mm.,[2] and dividing by the value of a second in radians we have

$$\alpha = \frac{1\cdot38}{s} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (4)$$

In consequence of the kind invitation extended by Prof. Holden, it was decided to make a practical test of the usefulness of the proposed method at Mount Hamilton.

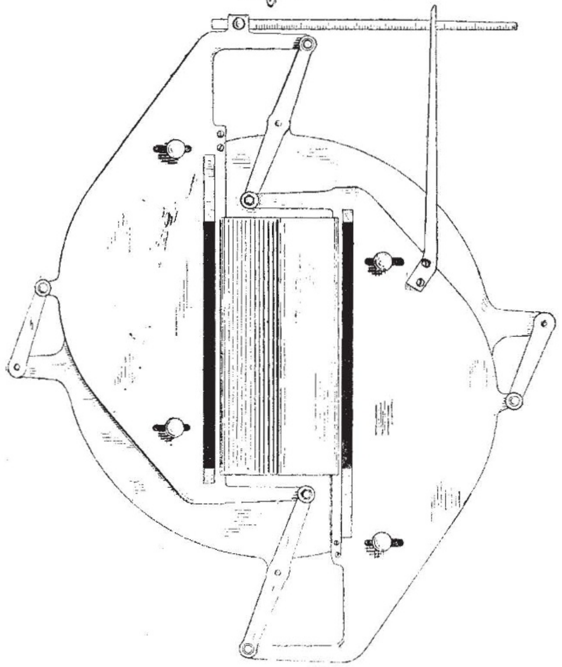
[1] *Philosophical Magazine*, July 1890.

[1] These will be superposed on another set of fringes due to diffraction from the edges of the slits; but the latter are too faint and broad to cause any confusion.

[2] The wave-length will, of course, vary somewhat with the object observed, but may be made constant by interposing a red glass.

For the preliminary experiments which are to be described it was thought desirable to use the 12-inch equatorial. Accordingly, a cap, provided with two adjustable slits, was fitted over the objective, and provided with a rod by means of which the distance between the slits could be altered gradually and at will by the observer, while the distance was measured on a millimetre scale attached to the sliding jaws. This arrangement, which was constructed under the supervision of Mr. F. L. O. Wadsworth, of Clark University, is shown in the accompanying diagram, Fig. 3.

Fig 3



With this apparatus the satellites of Jupiter were measured, with results as given in the following table :—

TABLE I.

No. of Satellites.	I.	II.	III.	IV.	Seeing.
	"	"	"	"	
August 2 ...	1·29 ...	1·19 ...	1·88 ...	1·68 ...	Poor.
August 3 ...	1·29 ...	— ...	1·59 ...	1·68 ...	Poor.
August 6 ...	1·30 ...	1·21 ..	1·69 ...	1·56 ...	Poor.
August 7 ...	1·30 ...	1·18 ...	1·77 ...	1·71 ...	Good.
Mean...	1·29	1·19	1·73	1·66	

These are the values of the angular diameters of the satellites of Jupiter as seen from the earth. To reduce these to Jupiter's mean distance these values are to be multiplied by 0·79, which gives for the final values—

I.	II.	III.	IV.
1"·02 ...	0"·94 ...	1"·37 ...	1"·31

For the sake of comparison these values are recorded in the following table, together with those given by Engelmann, Struve, and Hough, and the last column contains some results kindly furnished by Prof. Burnham with the 36-inch on the same date (August 7) as the last of the series by A. A. M. :—

TABLE II.

No. of Satellite.	A. A. M.	ENG.	ST.	HO.	BU,
I...	1 02 ...	1·08 ...	1·02 ...	1·11 ...	1·11
II.	0·94 ...	0·91 ...	0·91 ...	0·98 ...	1·00
III.	1·37 ...	1·54 ...	1·49 ...	1·78 ...	1·78
IV.	1·31 ...	1·28 ...	1·27 ...	1·46 ...	1·61

It was found impossible to see the reappearance of the fringes on increasing the distance, yet the results of Table I. show that the disappearance could still be sharply marked. Indeed the concordance of the observations made under different circumstances on different nights was even closer than was expected. With a larger telescope both the brightness of the fringes and their distance apart will be increased, and it may be confidently predicted that the accuracy will then be even greater.

The values given in the second column, "Engelmann," are probably more reliable than the succeeding ones, but it is well worth noting that the results obtained by interference agree with the others quite as well as these agree with each other.

It should also be noted that the distance between the slits was about four inches. It may therefore be stated that for such measurements as have just been described, a telescope sufficiently large to admit a separation of four inches—say a six-inch—suitably provided with adjustable slits is fully equal to the largest telescopes now used without them.

It is hoped that within a few months the 36-inch equatorial will be supplied with a similar apparatus and observations begun for the definite measurement of the satellites of Jupiter and Saturn and such of the asteroids as may come within the range of the instrument.

In concluding, I wish to take this opportunity of expressing my appreciation of the courtesy of Director Holden in placing all the facilities of the Observatory at my disposal, and of the hearty co-operation of all the astronomers of the Observatory, especially the valuable assistance of Prof. W. W. Campbell in making the observations. A. A. MICHELSON.

Mount Hamilton.

THE SAMOAN CYCLONE OF MARCH 16, 1889.

THE Samoan hurricane of March 16, 1889, is one of those historic storms that have been rendered for ever memorable by the episodes of disaster and gallantry that attended them; by the escape of H.M.S. *Calliope*, which forced her way out of Apia harbour in the teeth of the hurricane, amid the cheers of the brave American sailors, who, themselves face to face with imminent death, forgot for a moment their own dire peril in their admiration of the daring and successful act of seamanship that rescued their more fortunate brothers. Mr. Everard Hayden, of the U.S. Hydrographic Office, has lately issued a preliminary Report on this storm, which, despite the regrettable meagreness of the data at his command, has, nevertheless, a certain scientific interest, inasmuch as less is known of the cyclones of the Pacific than of those of most other tropical seas.

The Apia storm, like the cyclones of the South Indian Ocean, was evidently formed on the northern limits of the south-east trades, and was one of a series that were generated in this region in March 1889. The first of these, in Mr. Hayden's opinion, appears to have originated on the 5th of the month, some 500 miles north-north-east from the Samoan Islands, and to have travelled first in a south-westerly direction, recurving in the latitude of these islands, but at 150 to 200 miles to the west of them, after which it took a south-eastward course between Tonga and Nuië. It seems to have been a storm of great severity, and its passage was felt at Apia on the 6th and 7th, though not with any great intensity. It was succeeded by the cyclone that forms the principal subject of Mr. Hayden's Report. This, he thinks, was formed about March 13, some 300 miles to the north-east of the Samoan Islands, and on the 15th its centre passed either directly over, or a little to the north of, Apia harbour, moving, therefore, on a south-west course. He considers that it then sharply recurved, and that, with greatly increased strength, it passed a second time over Apia on the 16th, the day of the great naval disaster. The chief facts which led Mr. Hayden to this conclusion are those observed at Apia itself, for no positive evidence is forthcoming from the supposed birthplace of the storm, and only one ship reports the state of the weather anywhere to the north of Samoa. The peculiar feature of the Apia observations is, that the barometer fell steadily from the 12th to the afternoon of the 15th (about 0·7 inch), then rose (about 0·25 inch) during the latter part of that day, and then again fell on the 16th to a reading slightly lower than that of the previous day. On the 15th, squalls of moderate force (wind southerly, force 2 to 6) were experienced, and in the after part of the day, as the barometer rose, the direction changed from south to north and east. There had been no heavy sea, and it was thought that the gale was over. At midnight, however, the barometer began