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# CIRCUMZENITHAL ARC TANGENTIAL TO A CORONA OF 46°

By S. B. L. MATHUR
Physics Department, Lucknow University

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## INTRODUCTION

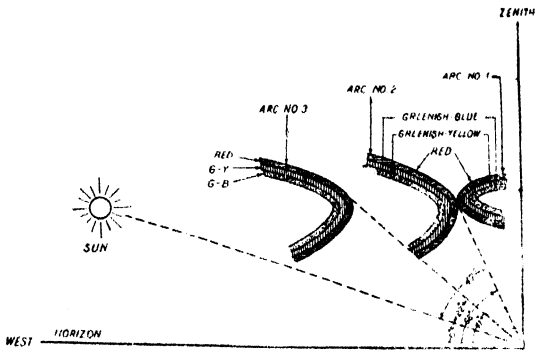
The object of the present paper is, primarily, to describe a rather unusual optico-meteorological phenomenon, and, secondarily, to offer a probable explanation. It must, however, be made clear that, as no measuring instruments of any type were available at the time of the occurrence of the phenomenon, accurate observations could not be taken. The explanation here offered is, therefore, merely a qualitative one.

## DESCRIPTION OF THE PHENOMENON

The phenomenon was noticed by the author, at Lucknow, on the 9th of September, 1939, between 4-45 p.m. and 5-5 p.m. It must, however, have been in existence sometime earlier than 4-45 p.m. as another observer, Mr. Rahat Husain Rizavi, then a student of the B.Sc. class in this University, who very kindly lent to the author his notes taken at the moment of observation, recorded 4-20 p.m. as the time when he noticed the phenomenon.

It had rained earlier in the afternoon ; and the sky, which was full of cirro-cumulus clouds around the zenith and of a stretch of dark cloud, probably of the cumulo-nimbus type, in the west and in the south, was just clearing. The author is not quite sure of the exact variety of that cloud as the formation was rather complex. He, however, later on learnt from a meteorologist that there were widespread thunderstorms in the west United Provinces on that date. Hence it is concluded that in the complex formation there must have been a good deal of cirrus spreading from the top of cumulo-nimbus clouds.

Some distance down the zenith towards the west there was, what appeared to the eye, a brightly coloured arc with its centre at the zenith and curvature convex towards the sun (arc no. 1). The red or orange hue, which was outermost, *viz.*, towards the sun, was followed by yellowish green and then greenish blue in the interior. The length was short—about one quadrant ; and the plane




of the arc seemed to be horizontal—at any rate it was not sharply inclined to the horizontal with the summit higher than the ends.

Tangential to the above arc was another (arc no. 2). But this was concave to the sun with the red or orange hue outermost, *viz.*, away from the luminary, followed by yellowish green and then greenish blue in the interior. The reds of the two arcs overlapped each other at the summit thus forming a tangency. The hues were less bright, but the radius and length were much greater than those of the first arc.

Further down the west, there was a third arc with a still bigger length but so faint as to be seen with difficulty. The sequence of hues was the same as in arc no. 2.

One had to face the sun in the west to see the three arcs.

The author saw the phenomenon from a small courtyard measuring 15′ by 13′. Unfortunately, as no measuring instruments of any type were available at the moment the author had to content himself with recording the sequence of hues and fixing in his mind, as well as he could, the position of the three arcs in the sky with the help of the various details in the courtyard hoping to make angular measurements with the aid of stars occupying analogous altitudes later on. In the absence of instruments it was fortunate that the courtyard was rather small as the position of the arcs could be better fixed in it than in an open space where no reference points would have been available. But, the rainy season being not quite over, it took quite a long interval of time before the sky was found to be clear at nights and any stars were found to occupy analogous altitudes. However, observations were made on various dates and at different times of the night. But it is obvious that, as our eyes are not trained to judge angular distances in the region of the zenith and as measurements taken long after the event are liable to be vitiated for faults of the memory, the data collected cannot be expected to have any great accuracy. The following observations will show for themselves the extent to which they may be relied on.

## MEASUREMENTS

The altitude of the sun at 4-45 p.m. on the 9th of September, 1939, was kindly calculated for the author by Prof. J. A. Strang, Head of the Mathematics Department, Lucknow University, as nearly 19 degrees.

The following table is given to show roughly the position of the three arcs in the sky. The angles were measured with a sextant.

Observations for the altitude of the

| Tangential arcs (1 & 2) at the place of contact | | | | | Arc no. 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Date | Time | Name of the star | Altitude | | Date | Time | Name of the star | Altitude |
| 1 | 8.10.39 | 8-30 p m. | α-Delphinus | 74° | 1 | 5.11 39 | 8-0 p.m. | α-Aquilae | 45° |
| 2 | 8.10.39 | 8-31 p.m. | α-Aquilae | 60° | 2 | 11.11.39 | 4 20 a.m. | β-Orion | 34° |
| 3 | 5.11.39 | 10-40 p.m. | γ-Pegasus | 70° | 3 | 11.11.39 | 7-35 p.m. | α-Aquilae | 45° |
| 4 | 6.11.39 | 3-15 a m. | α-Taurus | 67° | 4 | 13 11.39 | 5-50 a m. | α-Orion | 42° |
| 5 | 6.11.39 | 6-40 p.m. | α-Aquilae | 69° | 5 | 21.11.39 | 7-25 p.m. | α-Aquilae | 37° |
| 6 | 8.11.39 | 9-55 p. m | α-Pegasus | 62° | | | | | |
| 7 | 11.11.39 | 5-5 p.m. | γ-Gemini | 67° | | | | | |
| | | | Mean | 66° | | | | Mean | 41° |

It will thus appear that, roughly, the distance of the arcs 1 & 2 from the sun was (66° − 19°) *viz.*, 47° and that of arc no. 3 was (41° − 19°) *viz.*, 22°.

## DISCUSSION

It is obvious that, as the above observations were, at the best, very rough, they can scarcely serve as the basis of any conclusions. The author is, however, sure of the accuracy of his observations as regards the sequence of hues in the arcs as he took notes about this at the time of the occurrence of the phenomenon. As a matter of fact, the sequence of hues was the only aspect of the phenomenon about which he could be sure. Further, when difficulties were found in explaining the event, the author had the good fortune of having his observations in this respect corroborated by the independent evidence of Mr. Rizavi, who saw the phenomenon from a place about 3 miles to the north and recorded his observations at the time of the occurrence. Mr. Rizavi did not see arc no. 3 which at 4-45 p.m. was found to be very faint by the author. The explanation here offered is, therefore, entirely based on the sequence of the hues in the arcs.

(*I*) *Arc no. 1*

At first the author thought that the arc no. 1 was a rainbow of the 3rd or the 4th order, as it was visible on the same side as the sun. From the simple relations

$$\cos i = \sqrt{\frac{\mu^2 - 1}{n^2 + 2n}}$$

and

$$D = 2(i - r) + n(\pi - 2r)$$

it is easy to calculate that for the red H-line $\lambda = 6562.9$ A°, $\mu$ being equal to 1.3311, the angle D, of deviation, for $n = 3$ and $n = 4$ are $(2\pi - 42° 30')$ and $(3\pi - 137° 10')$ respectively. The deviated red rays will, therefore, make angles of 42°30′ and 42°50′ with the horizontal for the tertiary and quarternary rainbows respectively. Since the sequence of hues in the tertiary is the same as that in the primary, *viz.*, red outermost, the arc should be a tertiary rainbow. Further, the section made by the screen of water drops of the cone formed round the line joining the sun with the observer and having an angle of $42\frac{1}{2}°$ will be convex to the luminary—just the type of curvature found in the arc.

But there were two main reasons which went against the view that the arc was a rainbow. Firstly, the intensity of the hues was so strong as to be comparable to a primary bow, whereas, in a tertiary, the intensity should be extremely small. Indeed, although cases are on record when, under exceptionally favourable circumstances, tertiary, or even quarternary, rainbows have been seen,[1] some authors go so far as to say that " rainbows of order higher than the second are not to be seen in nature." [2] Secondly, the centre of the bow must lie on the line joining the observer to the sun so that the plane of the bow must be steeply inclined to the horizontal. The author is quite definite that the arc seemed to lie more or less in a horizontal plane and had its centre at, or near, the zenith.

As the arc was convex to the sun, the former could not have been a halo or a corona. But, all indications point to the conclusion that it was a circumzenithal arc.

A circumzenithal arc is an arc of 90°, having its centre at the zenith, and is seen at some 46°, or a little more, above the sun. It is said that it lasts only a few minutes, but during this time it is often so brilliantly coloured—red on the outside to violet inclusive—as to be mistaken for an exceptionally bright rainbow. It occurs most frequently when the altitude of the sun is about 20° and at times when the parhelia of 22° are conspicuous.

It will thus be seen that, apart from the absence of parhelia, the description of the circumzenithal arc tallies in all essential details so well with what was actually observed that one feels almost certain that arc no. 1 was a circumzenithal one. The presence of cirro-cumulus clouds, thus ensuring the existence of ice

crystals necessary for the production of the arc, the inclination of 47° of the arc with the sun, the intensity and the sequence of the hues and, finally, the location of the centre at the zenith—all point to the same conclusion. Incidentally, it will be seen that the mean of the various values found for the distance of the arc from the sun, *viz.*, 47°, appears to be wonderfully near the mark—a strange coincidence.

In passing, it may be added that circumzenithal arcs are formed when the principal axes of a large portion of ice crystals are practically vertical, *i.e.*, when the snow crystals are largely columnar with tabular caps, or more likely, perhaps, merely tabular. They have been explained by Bravais [3] as being due to refraction of light through snow crystals in still or steadily flowing air, when the crystals keep their principal axes substantially vertical. Since they are formed at an angle of 46° with the sun, they will be tangential to the 46° halo, if the latter also occurs at the time.

(2) *Arcs nos. 2 & 3*

Since arc no. 1 has been established to be a circumzenithal arc at a distance of 47° from the sun, the radius of the concave arc no. 2 must be 47°. This fact emerges from the observation that the two arcs were tangential to each other at the summit and is apart from the measurements which are, by no means, to be considered as accurate. The measurements, however, happen to confirm this conclusion, and one feels inclined to believe that the measurements made on the 3rd arc may not be very incorrect.

Arcs round the sun at angles of 46° and, presumably, 22° occurring in the presence of cirro-cumulus clouds have every chance of being the well-known halos of 46° and 22°. However, the colour sequence, *viz.*, red outermost, is definitely of the type that occurs mainly in diffraction and not in refraction phenomena. Further, it is well-known that, of the two, the 22° halo is the more intense, whereas the opposite was found to be the case—the arc nearer to the sun being scarcely visible. It is true that diffraction also may play a rôle in the formation of halos. Visser [4] has taken diffraction into account in an attempt to explain better the features of a halo, but, even then, the red hue occurs at the inner edge and not at the outer.

Hence, unless there is some particular process of refraction of light from snow crystals, which is hitherto not known, and, which produces halos of 46° and also of about 22°, with the colour sequence reversed, the arcs in question will have to be classed as coronas. On the other hand, coronas with such well-defined rings of large angles like 46° have never been known to occur. The only instance of large-radii corona known is that of Bishop's rings which were observed in 1883, and again in 1903, after the eruptions of Krakatoa and Mt. Pelee respectively, and had a radius of only 22° for the red hue. Iridescent clouds,

which Simpson[5] and Brooks[6] hold to be portions of coronas, and are produced by the diffraction of light by water drops, have been found by the latter to occur at even 60° from the sun. But, the author did not notice any colour patches of which the ares 2 and 3 could be considered as end fringes.

It will, perhaps, be of interest to derive the size of the diffracting particles for rings of size 46° and 22° respectively. As the intensity of the 46° arc was greater than that of the 22° one, it would be reasonable to postulate that the former was not merely a higher order corona of the latter. Hence, there must have been diffracting bodies of two different sizes present in the atmosphere.

Using the simple relation $\theta = \lambda/2a$ the size of the drops responsible for the 22° corona would be 1·9 $\mu$ and of those producing the 46° one would be 0·9 $\mu$. It will thus appear that the size of the diffracting body is about the same as that of the light waves themselves. It must, however, be said that the relation between the radius of the corona and the size of the diffracting body has not yet been satisfactorily worked out in the case of very small water drops.

The author would like to thank Prof. J. A. Strang of the Lucknow University for kindly calculating the altitude of the sun, Mr. Rahat Husain Rizavi, B.Sc., for placing his records at the disposal of the author thus enabling him to confirm his observations about the colour sequence of the arcs at the time when he began to doubt their correctness, and Mr. R. K. Joardar, B.Sc., for drawing the diagram for this paper. A few other gentlemen also helped the author with their verbal reports, but, as they had not made any accurate records, their evidence was not of much value beyond corroborating some of the features of the two tangential arcs.

## SUMMARY

A remarkable optico-meteorological phenomenon was seen in Lucknow on the 9th of September, 1939, between roughly 4 and 5 p.m. Although no measurements could be taken at the time, the author, from considerations of the intensity of the hues and their sequence in the two tangential arcs in the sky, concludes that he saw a circumzenithal arc tangential to a corona of 46°. Further, he found another arc further down in the west which was probably another corona of 22°. Although coronas of such large radii have not been known and radii of 46° and 22° are strongly suggestive of the well-known halos of those angles, the sequence of the hues is definitely in favour of two of the arcs being coronas and not halos. If the conclusions drawn are correct, this paper gives the first record of a circumzenithal arc being tangential to a corona and of the possibility of coronas of large sizes like 46°.

PHYSICS DEPARTMENT,
LUCKNOW UNIVERSITY.

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