,ALONGKORN UNIVERSITY
DEPARTMENT OF EDUCATIONAL TECHNIQUES (MINISTRY OF EDUCATION)
APPLIED SCIENTIFIC RESEARCH CORPORATOIN OF THAILAND

COOPERATIVE RESEARCH PROGRAMME NO. 4
SOLAR FLARES IN RELATION TO RADIO COMMUNICATIONS
AND STUDY OF ALLIED SOLAR PHENOMENA

RESEARCH PROJECT NO. 4/1
OPTICAL OBSERVATION OF THE SUN'S CHROMOSPHERE

REPORT NO. 5
A STUDY OF THE COMPLEX SUNSPOT GROUPS OF 20 NOVEMBER – 1 DECEMBER 1967

BY
SACRAN PATANAVANICH
SOLAR PHYSICS UNIT
TECHNOLOGICAL RESEARCH INSTITUTE

ASRCT, BANGKOK 1968
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F O R E W O R D

Research Programme No. 4 is a cooperative venture between the Department of Physics, Faculty of Science, Chulalongkorn University; the Department of Educational Techniques, Ministry of Education; and the Applied Scientific Research Corporation of Thailand. As part of this work visual observations on solar phenomena are being carried out at the Solar Observatory at the Bangkok Planetarium, Sukhumwit Road, Bangkok.

The present report is part of the research undertaken by Miss Sacran Patanavanich as part of the requirements of her work for the degree of Master of Science at Chulalongkorn University on a scholarship provided by ASRCT.

A STUDY OF THE COMPLEX SUNSPOT GROUPS OF 20 NOVEMBER - 1 DECEMBER 1967

By Sacran Patanavanich*

SUMMARY

The development of two nearby sunspot groups of 20 November - 1 December 1967 were studied in the light of Babcock's theory on the formation of sunspot groups. Both groups seemed to be produced by a single flux rope of the same turn, but analysis of the data indicates that they were not from the same origin.

I. INTRODUCTION

Since January 1966 a programme of solar observations has been in progress at the Observatory of the Bangkok Planetarium, Sukhumwit Road, Bangkok, and as part of this programme, interesting sunspot groups have been selected on occasions for extended high resolution studies of their development. The sunspot groups which appear near the east limb of the solar disk on 20 November 1967 were studied during their transit across the disk which is shown on Figure 1. Photographs were taken every day from 20 November - 1 December 1967 with the 150-mm Zeiss coudé refractor of the Sukhumwit Observatory. This report describes the development of these complex sunspot groups.

Sunspots appear on the surface of the sun by the emergence of solar magnetic flux ropes in the photosphere. According to Babcock (1961), the weak poloidal field of the sun, strength 1-2 gauss, has shallow submerged lines of force, which are distorted by the solar differential rotation. These lines are drawn out in longitude to form rather tight spirals or toroidal fields on opposite sides of the solar equator. This continues until the magnetic energy of the submerged toroidal fields locally attains a critical limit, and instabilities occur. Magnetic bouyancy will lift the concentrated flux ropes to the surface. The

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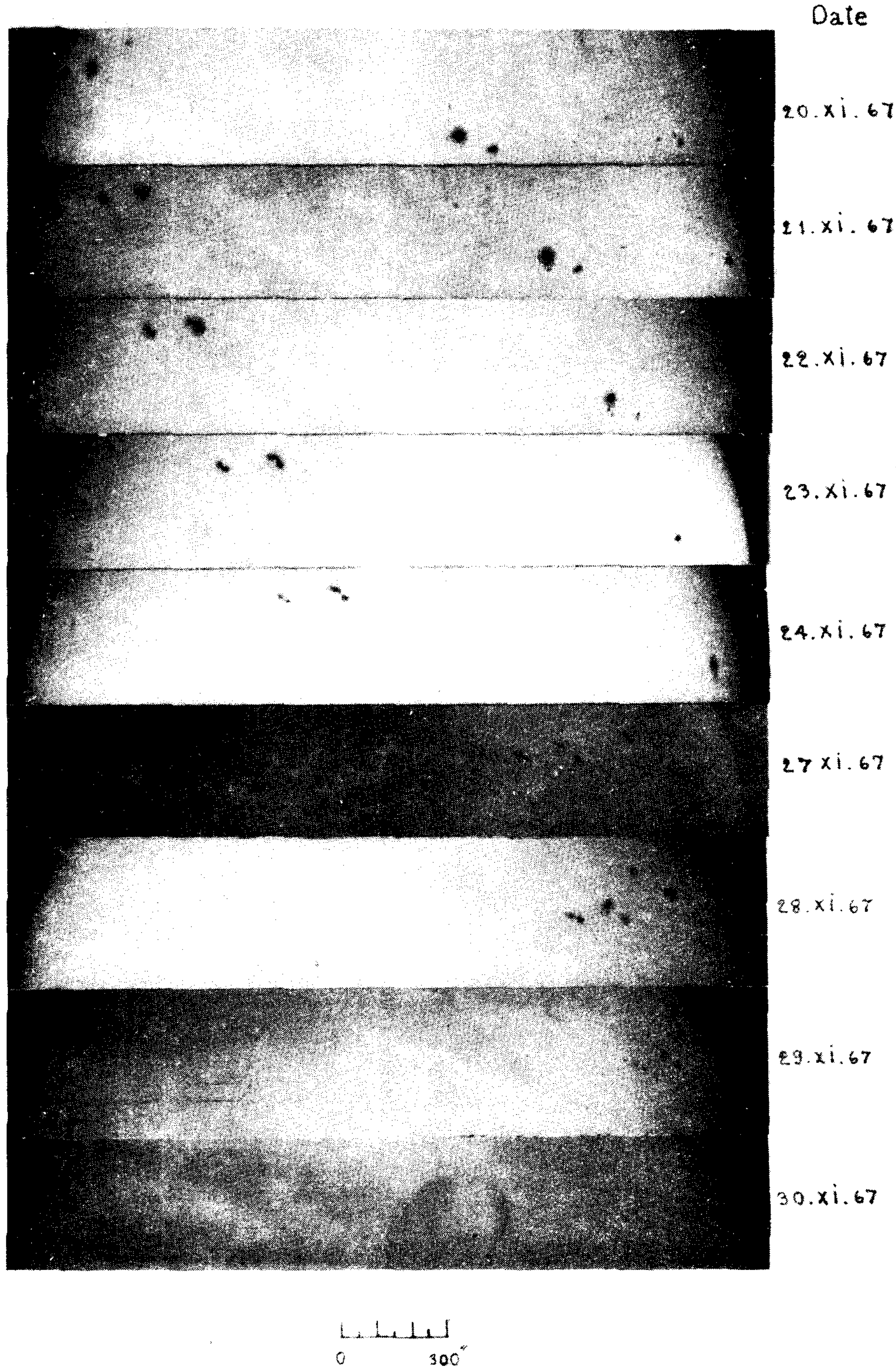


Figure 1.—The apparent transit of sunspot groups across the solar disk caused by the rotation of the sun. Photographs taken at the Sukhumwit Observatory, Bangkok.

lines of force cut the solar surface at two adjacent equal areas of opposite polarities, which are referred to as the preceding part and the following part in relation to the rotation of the sun. These two regions, which are produced by each loop, are called bipolar magnetic regions, and bipolar magnetic regions in the two hemispheres have inverse polarities. Sunspots occur within bipolar magnetic regions wherever the lines of force are sufficiently concentrated to inhibit convection on the solar surface.

As a consequence of differential rotation, the spiral winding of the toroidal field is tighter in moderate latitudes than near the equator; so sunspots first appear at moderate latitudes at the beginning of the sunspot cycle and then progress to lower latitudes at the end of the cycle.

II. GENERAL CHARACTERISTICS OF A SUNSPOT GROUP

A sunspot group first appears as one or more sunspot pores. Most groups do not develop beyond this stage, and they usually disappear by the following day. Groups that have survived continue to develop rapidly to maximum area and then slowly decline. According to Waldmeier (1955, quoted from Bray and Loughhead 1964), the lifetime of a sunspot group is related to its maximum area by the rule

$$T = 0.1 A_{max}$$

where T is the lifetime in days and A_{max} is the maximum area in millionths of the visible hemisphere. The area of a sunspot is related to its magnetic field strength. The lifetime of a sunspot group ranges from one day to more than one hundred days. The frequency of occurrence decreases rapidly with increasing lifetime. The Zürich classification of sunspot groups is used to describe their development. Large sunspot groups pass through all classes during their lifetime, whilst medium sunspot groups and small sunspot groups only pass through some classes.

The presence of a sunspot generally has no effect on the surrounding granulation except in the case of new and developing spots, which occasionally cause disturbances in the granulation pattern. Dark lines have been observed developing between two groups of pores of opposite polarities. Bray and Loughhead (1964) interpreted this phenomenon as evidence of the existence of a rising loop of magnetic flux. The development of a sunspot pore during the first day is rapid because of the increase of magnetic flux in that region. Most pores with diameter exceeding 5 sec of arc will develop into small spots having a penumbral structure surrounding them. Both the umbra and the penumbra develop with increasing area. The structure of a well developed penumbra depends on the size and the stage of its evolution. Most penumbral structures are filamentary, tending to run radially outward from the umbra to the photosphere.

In most spots there are various kinds of bright features which are classified into three distinct morphological types by Bray and Loughhead (1964). Bright regions are also found in the umbra of most spots, and these are called light bridges. They show great diversity in shape, size, and brightness. They may be in the form of large masses of bright material or of thin streamers of about 1 sec of arc in width. Some bridges are brighter than the photosphere and some are so faint as to be seen only on over-exposures. Light bridges are often stable and long-lived. Most of them have a lifetime of at least several days. They often occur at one side of the umbra and then extend to the other side of the umbra, and the appearance of light bridges in the umbra of a spot during the later part of its life is frequently a sign of final dissolution.

III. INSTRUMENTATION

The Zeiss coudé refractor of 150 mm diameter and 2,250 mm focus is mounted in the dome of the Observatory which is about 3.75 m in diameter. The dome is about 20 m above the ground thus avoiding the turbulent layers of the atmosphere which produce bad solar seeing. The telescope has an achromatic objective on an equatorial mounting as shown in Figure 2. A plane mirror, 150 mm diameter, is situated at the end of the telescope tube. The converging light beam from the objective is reflected at the first mirror to a second mirror of 140 mm diameter situated in the polar axis. The second plane mirror can be tilted to two alternative positions, perpendicular to each other, to provide two positions of coudé focus for observations, one at the front end and the

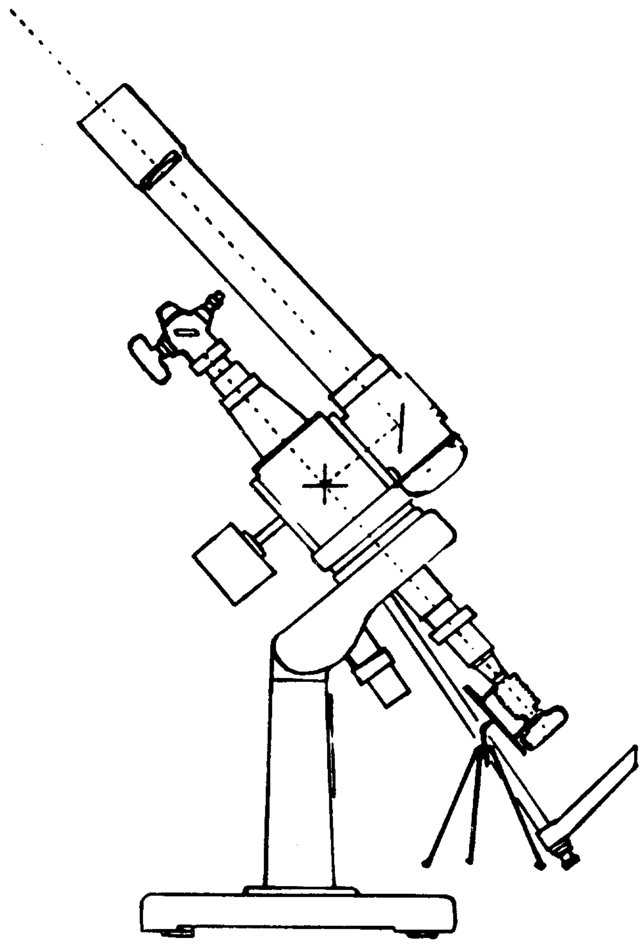


Figure 2.—The 150-mm Zeiss coudé refractor showing position of camera attachment for photographic observation.

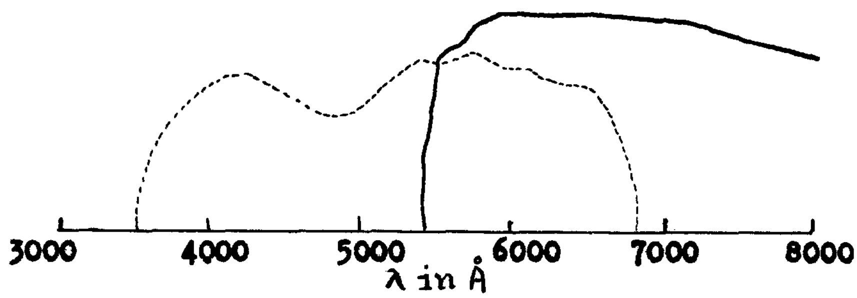
other at the rear end of the polar axis. A projection screen is located at the rear end. The telescope is driven by a synchronous motor with three different speeds for the sun, the moon, and fixed stars. It is coarsely set in both axes by means of cranks which can easily be operated from the observer's seat, and is finely set by means of manually operated potentiometers.

Visual observations of the solar disk are made at the rear end of the telescope by projecting the solar image onto the screen. Photographic observations are made both at the front end and the rear end of the telescope, the front end for first image photographs and the other for enlarged image photographs. At the front end, a double eyepiece revolver with an uncoated plane mirror designed for solar observation is used to cut down the intense radiant energy. An orange filter (OG2) and a 35 mm Exacta camera have been fitted to the revolver to photograph the whole disk image. The average diameter of the solar image is about 20 mm depending upon the actual distance of the sun on the particular day of observation. A selected filter and a 10-mm eyepiece are used at the rear end with the camera. In most observations, an OG2 orange filter, or an RG2 or RG5 red filter, is used. The OG2 and the RG2 filters are more transparent than the RG5, and a 1 per cent neutral filter is used with them to reduce the radiation intensity. The image size at the rear end, with adjustment to 10 times magnification over the first image, has a diameter of about 200 mm.

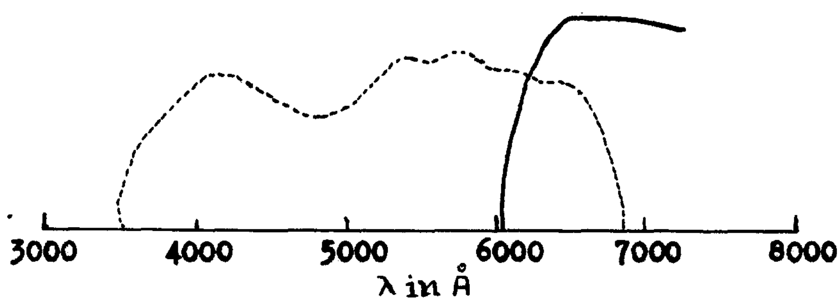
IV. OBSERVATION AND REDUCTION

Photographic observations were made with the 150-mm Zeiss coudé refractor every day from 20 November to 1 December 1967. On each day the observations were usually taken between local time $09^h\ 00^m$ to $16^h\ 00^m$. The good solar seeing moments occur between $11^h\ 00^m$ to $13^h\ 00^m$. The first images were taken through the OG2 filter, and the enlarged images through the OG2 and the RG5 filters using Gaveart Duplo Pan Rapid roll film. The response curves of the emulsion and the transmission curves of various filters are shown in Figure 3. Development was undertaken in a tank using Kodak D76 developer at 20°C for 9 minutes.

Enlarged prints have been made from good quality negatives with an



(a)



(b)

Figure 3.—The response curve of Duplo Pan Rapid emulsion and transmission curves of filters (a) OG2 and (b) RG5.

enlargement of 10 times the original size on high contrast Agfa BS1 paper. The print scale is 10.8 mm to 10 sec of arc.

V. DESCRIPTION OF THE COMPLEX GROUP OF 20 NOVEMBER - 1 DECEMBER 1967

Two medium sunspot groups appeared on the east limb of the solar disk on 20 November 1967. At first they appeared to be a single group of class D, but from the later observations it is evident that they were two separate groups. For convenience, the larger group is called the W group, and the smaller one, the E group. Between these two sunspot groups, several pores appeared, as shown on Figure 4. The faintest pores at the left near the W group developed further and extended to the W group as the following part of the group. Other pores, which had occurred between the two groups and had persisted for five days, appeared very faintly on 24 November and then disappeared on the following day. The pores above the E group developed on 21 November like a class B sunspot group and disappeared by the following day. Unfortunately, the resolution of the photographs is not good enough to show the details in each spot. Bright regions were found between the two small umbrae in the large spot of the W group and at the lower part of the umbra of the E group.

The W group developed further as shown on Figures 5 and 6. It gradually moved to the centre of the solar disk with increasing area. A light bridge at the right of the largest umbra began to invade through the umbra on 21 November. The umbrae developed and became larger and larger, the lower part of the largest umbra extending and elongating. A light bridge at the lower edge of the largest umbra appeared on 22 November and invaded the upper edge. These two light bridges divided the umbra into three parts on 23 November. Small umbrae at the right of the spot developed and combined into two elongated umbrae on 22 November. The left part of one elongated umbra near the largest umbra separated from the rest to combine with the right part of the largest umbra to form the third part. So there were five large umbrae in the main spot on 23 November. The faintest pore near the group became active and expanded, forming several small sunspots following the main spot. The

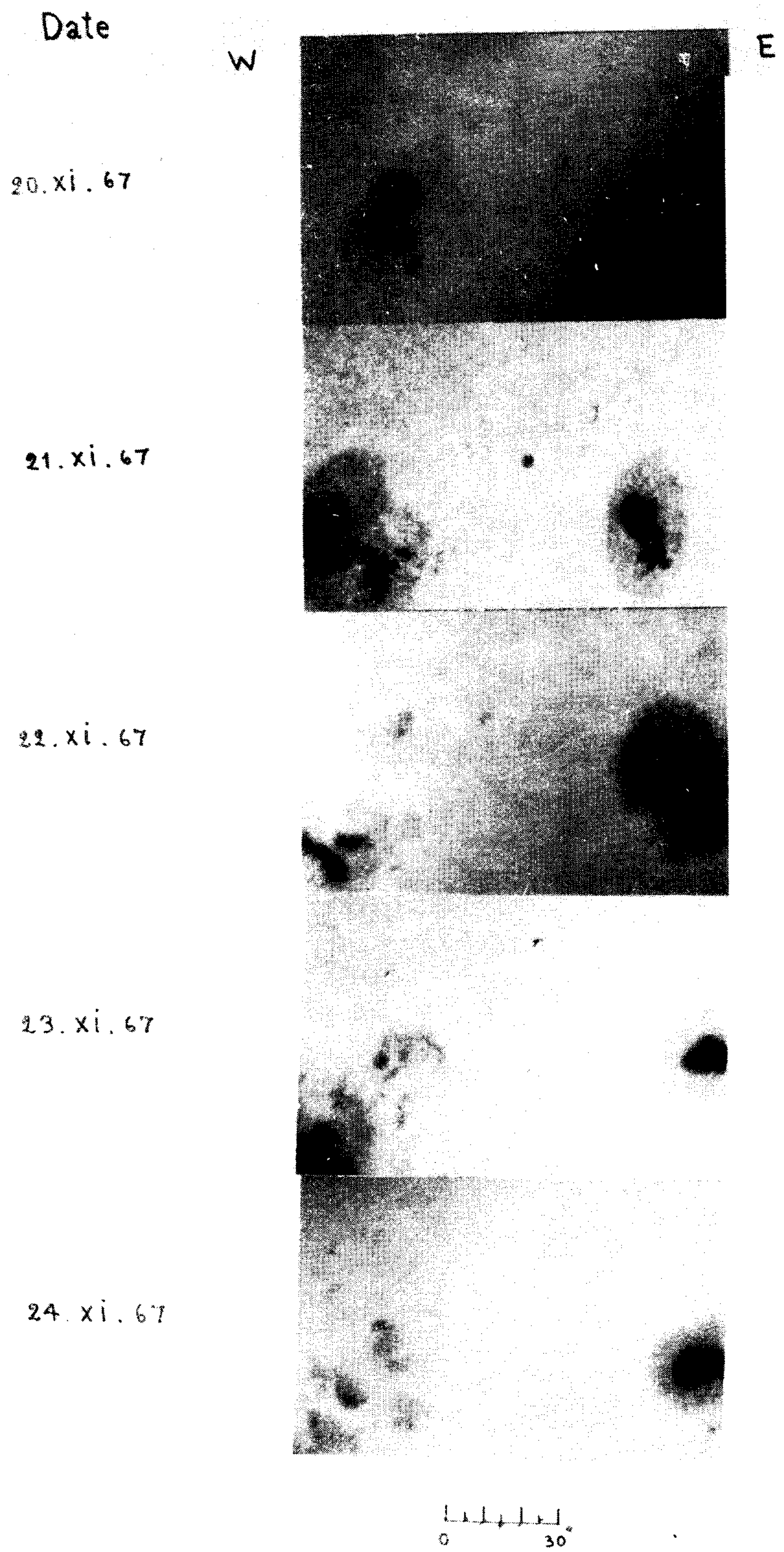


Figure 4.—The development of pores between two sunspot groups.

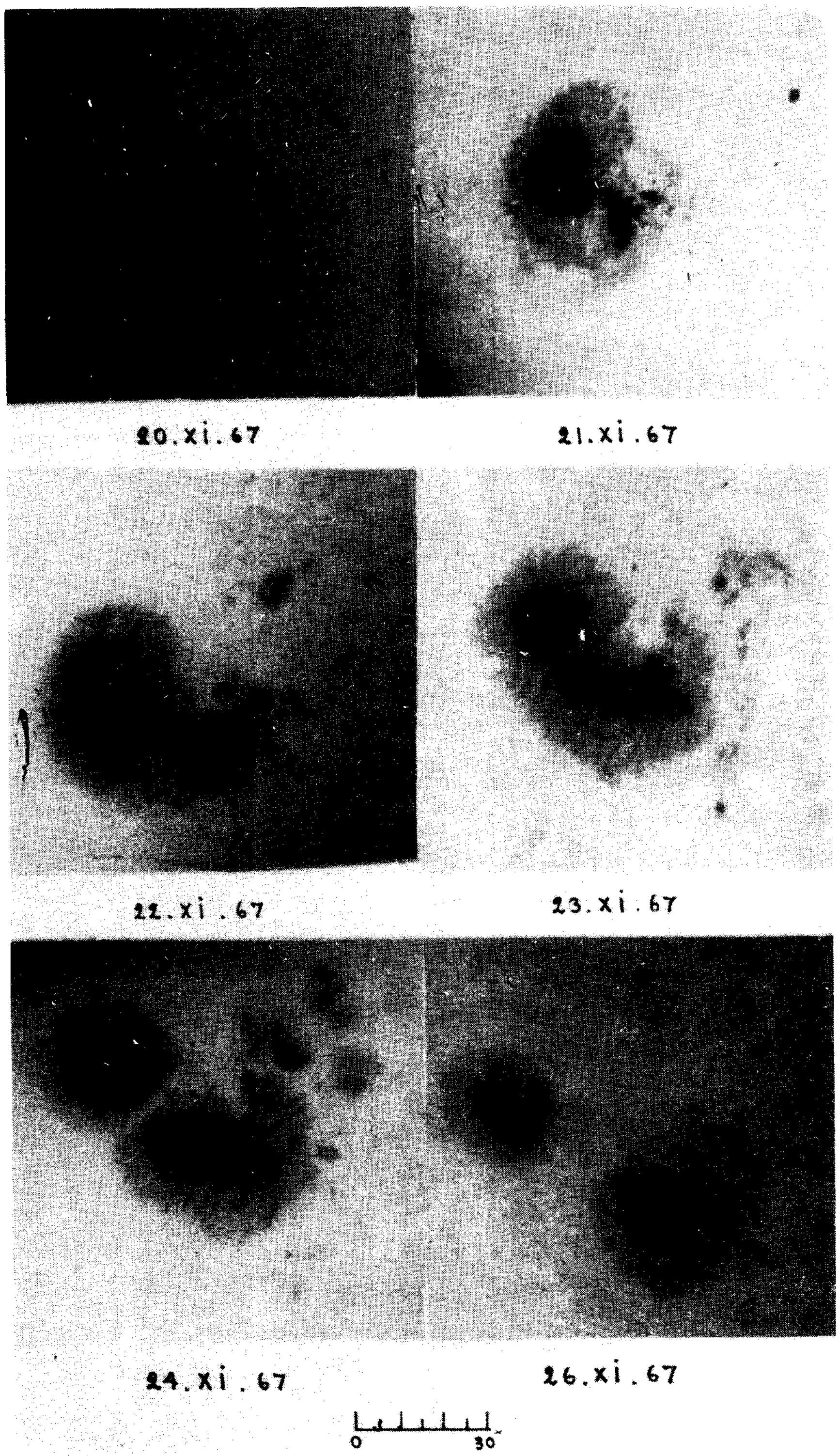


Figure 5.—The development of the W-sunspot group.

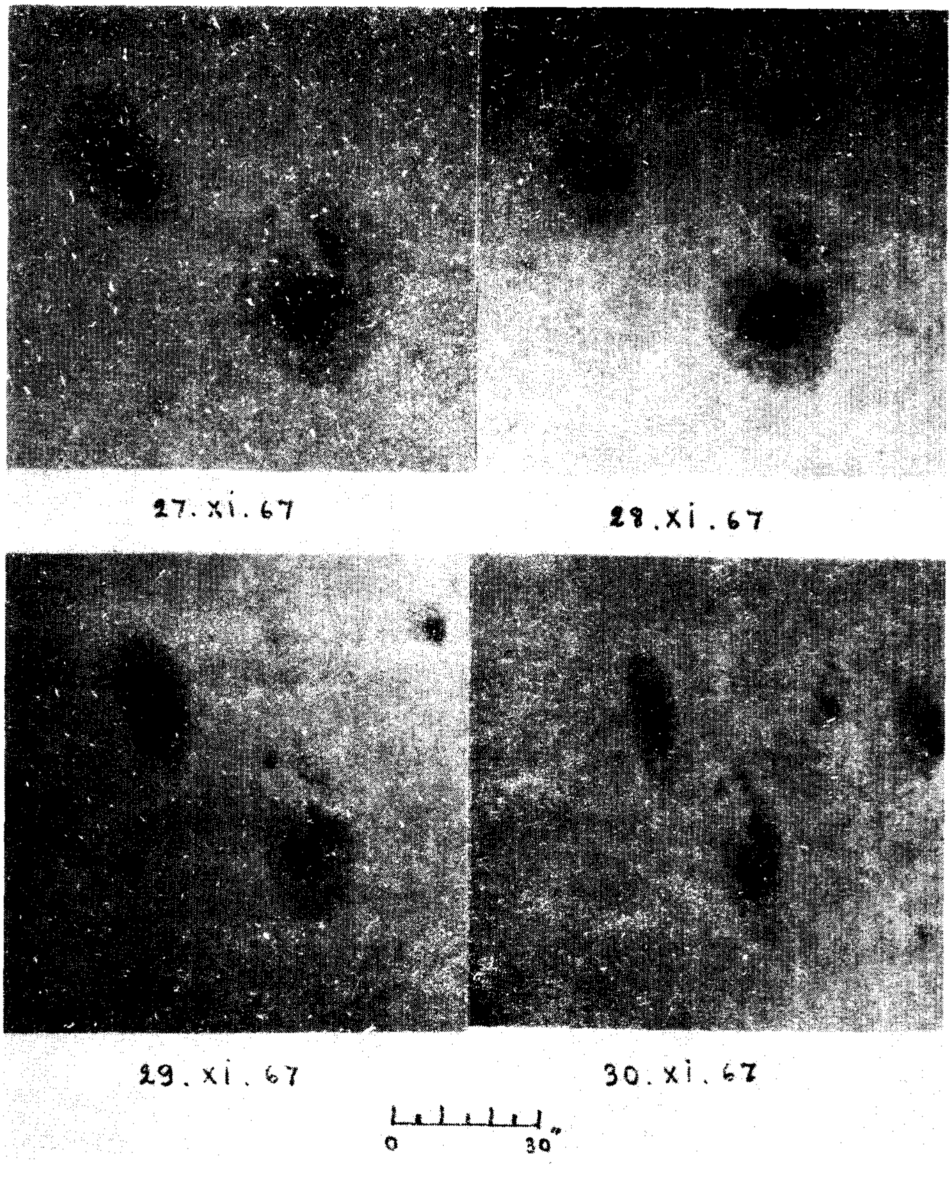


Figure 6.--The declining phase of the W-sunspot group.

bright region at the upper right part of the penumbra of the main spot still persisted and seemed to invade through the penumbra to separate into two main spots on 23 November. On 24 November the two main spots began to move apart. The left, nearly roundish spot, was the preceding spot while the right elongated one (combined from 4 umbrae), with the several small spots were the following spots. The group tended to a maximum on 24 November and then gradually declined. The small following spots began to disappear. The group slowly moved toward the west limb. The umbra of the main following spot broke into three parts on 28 November. The preceding umbra did not break but the area decreased. A bright streak appeared in the penumbra near the upper left part of the main following umbra on 28 November at local time $10^h\ 43^m$ and brightened up at $11^h\ 09^m$ as shown in Figure 7. It consisted of bright blobs connected together and persisted until the last observation on that day at $16^h\ 07^m$. The group was at the west limb on 1 December, the last day of observation for this group.

The E group slowly developed as shown in Figure 8. On 22 November, the umbra broke into two major parts and one small part at the lower end. There was a bright region in the penumbra at the lower left part of the upper umbra. The penumbra began to be divided by this bright region. The lower small umbra expanded to combine with the large one. The two large umbrae moved apart with the penumbra surrounding them and bordered by the bright streak on 23 November. The upper "preceding" spot and the lower "following" spot slowly moved apart and entirely separated on 27 November, and then began to decline. A bright bridge invaded the left of the following umbra on 24 November to separate the umbra which showed the beginning of the declining phase. On 29 November a sunspot group occurred near this group, having the main spot above the group and several pores to the east of the group. This new group still appeared and moved toward the west limb by the solar rotation with the old group. They were seen on the west limb on the last day of observation.

VI. DISCUSSION AND CONCLUSION

The development of these two sunspot groups followed Babcock's theory (1961) of the formation of a BMR. A submerged flux loop is brought

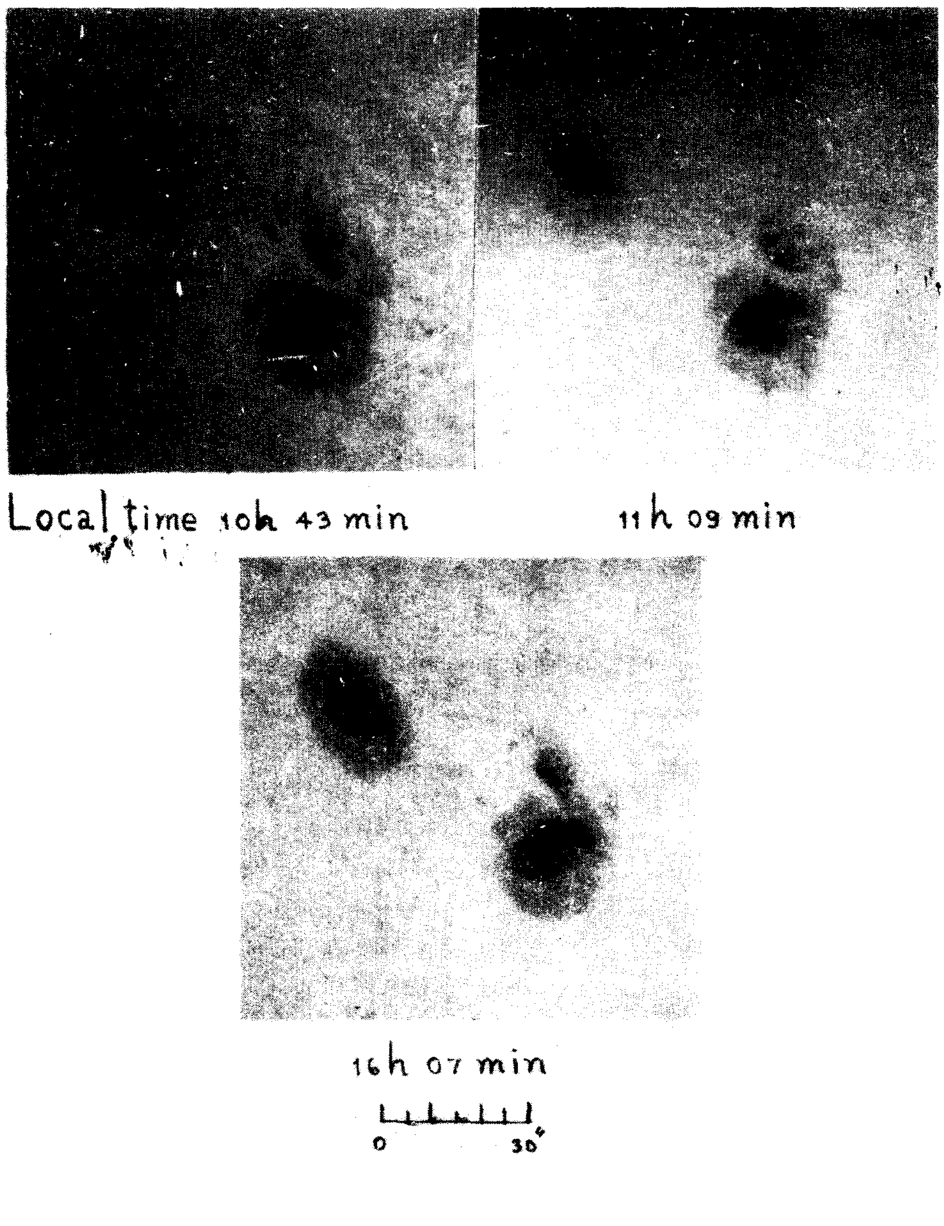


Figure 7.—A bright streak in the penumbra of the main following spot of the W-sunspot group shown on 28 November 1967.

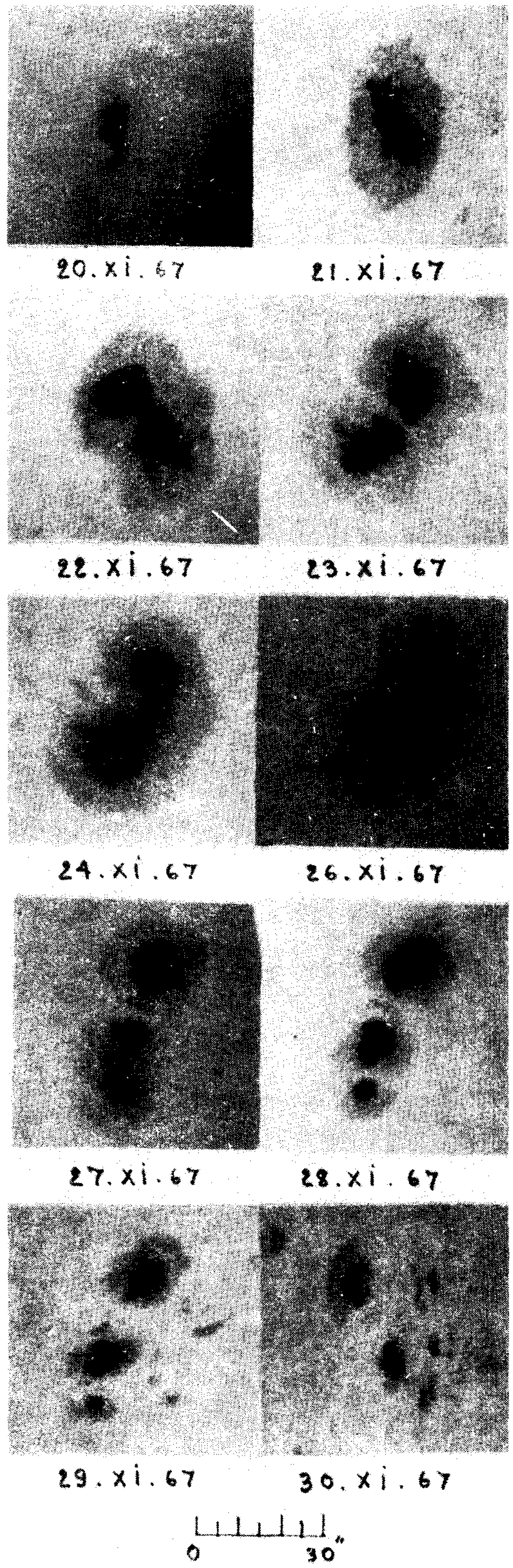


Figure 8.—The development of the E-sunspot group.

to the surface by magnetic bouyancy and first breaks the surface at one region with condensed flux. This is the region where a small spot or pore starts to form. Then the flux loop continues to rise, and the disturbed region breaks into two contiguous regions as shown in Figure 9. These regions are compact and may quickly produce spots or other form of activity as shown in the observations on 21-24 November. The magnetic flux gradually arches into the atmosphere which causes the lines of force on the surface to spread out. The apparent spots will break. The preceding and the following parts continue to spread, the field intensity diminishes, the decline begins, and finally the spot disappear. These phenomena are shown on photographs of 25 November to 1 December. Both groups disappeared from the solar disk by solar rotation, but they were still on the surface of the non-visible hemisphere for several days before diminishing to merge into the undisturbed region.

The present sunspot cycle is the 21st cycle and it began in 1966. Babcock postulated that the latitude at which the field is adequate to induce sunspot activity is given by

$$\sin \phi = \pm \frac{1.5}{n + 3}$$

where n is the number of years elapsed since the beginning of the cycle and ϕ is the latitude. The activity zone in 1967 is between the latitudes $\pm$ 22° at the beginning of the year and $\pm$ 17° at the end of the year. From calculation we find that the W group was at latitude about + 20°.5 and longitude about 324°; and the E group was at latitude about + 19°.4 and longitude about 315° on 20 November. As Wolfer (1899, quoted from Babcock 1961) has stated, sunspots tend to recur in preferred zones where there has been prior activity and Babcock's theory can explain this phenomenon. When a submerged flux loop is first formed due to excess twisting, the plasma within the rope must be squeezed longitudinally away from the constriction. After the loop has risen to the surface, the BMR begins to spread in area and the plasma required for the expanding BMR can be supplied only by longitudinal movement of material along the flux rope. Therefore the adjacent section of the flux rope, not greatly displaced from the apparent BMR, will become constricted with increase in field strength, and is likely to produce a new BMR close to the old one, but predominantly on the following or easterly

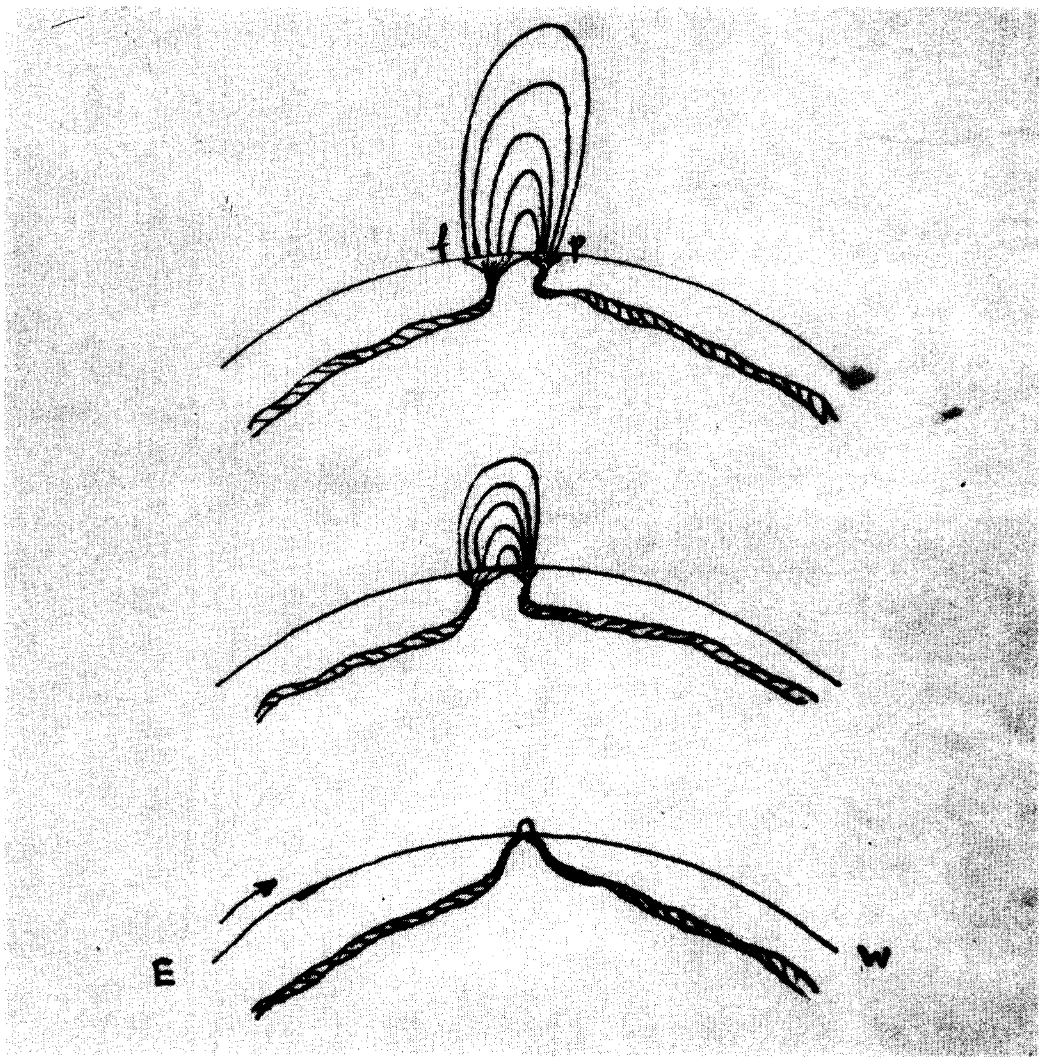


Figure 9.—The formation of a BMR according to Babcock (1961).

side.

Consider these two sunspot groups which occurred close together. They probably resulted from the same flux rope as mentioned above with the W group as the old activity region and the E group as the new one. If this were so:

(1) the E group should develop after the decline of the W group, and

(2) the angles that the axis of sunspot groups makes with the meridian should be the same or nearly the same.

We could not observe the beginning of the appearance of both groups and did not know which group appeared first. But from the observations of their development it can be estimated that they appeared nearly at the same time. Reduction of the data of 23 November and 27 November, using the method described in Report No. 3 in this series, gives the results set out in Table 1. (The calculations are given in the Appendix.) The inclination of the axis of the W group is 0.66 while that of the E group is 0.45 on 23 November; and on 27 November the inclination of the axis of the W group is 0.96 while that of the E group is 0.63.

TABLE 1

HELIOGRAPHIC COORDINATES OF SUNSPOTS

Date			B	L
23.xi.67	W group	preceding spot	$20^\circ.59$	$325^\circ.50$
		following spot	$21^\circ.56$	$324^\circ.03$
	E group	preceding spot	$19^\circ.13$	$315^\circ.60$
		following spot	$19^\circ.74$	$314^\circ.21$
27.xi.67	W group	preceding spot	$18^\circ.42$	$325^\circ.87$
		following spot	$20^\circ.78$	$323^\circ.42$
	E group	preceding spot	$18^\circ.66$	$316^\circ.49$
		following spot	$19^\circ.46$	$315^\circ.22$

Neither before nor after the separation of the two main spots of these two sunspot groups are the inclinations of the axes of these groups equal. Hence it is concluded that these two groups did not result from the same flux rope of the same turn. They may have resulted from the same flux rope, but belonged to different turns or resulted from separate ropes. Babcock estimated that the submerged flux consisted of eight ropes because he found that the total magnetic flux in the polar cap was 8×10^{21} maxwells or eight times that of a typical sunspot group or BMR, i.e. 10^{21} maxwells. We still do not know how these eight ropes are arranged before and after amplification. It needs more observations and computation to find out their arrangement.

VII. ACKNOWLEDGEMENTS

I wish to thank Dr. Rawi Bhavilai for his guidance throughout this work. I also express my gratitude to the Applied Scientific Research Corporation of Thailand for its support through the grant of a scholarship and other assistance, to the Ministry of Education for permission to use the telescope, and to my colleague Mr. Manit Avuchanonda for assistance in observations.

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APPENDIX

CALCULATIONS

Following the method used in Report No. 3 of this series, the heliocentric coordinates of sunspots on 23 November and 27 November 1967 are found. Then the inclination of the axes of the sunspot groups are determined :

	23.xi.67	27.xi.67
The position angle of the axis of rotation of the sun (P)	$19^\circ.19$	$17^\circ.81$
The heliocentric latitude of the centre of the sun (B_0)	$1^\circ.90$	$1^\circ.39$
The heliocentric longitude of the centre of the sun (L_0)	$347^\circ.74$	$294^\circ.82$
The position angle of the preceding spot of the W group	$67^\circ.00$	$-41^\circ.00$
The position angle of the following spot of the W group	$67^\circ.00$	$-35^\circ.40$
The position angle of the preceding spot of the E group	$78^\circ.50$	$-31^\circ.70$
The position angle of the following spot of the E group	$78^\circ.50$	$-28^\circ.70$

The ratio of the distance of the spots from the centre of the disk and the radius of the disk are:

	23.xi.67	27.xi.67
The preceding spot of the W group	0.4800	0.5743
The following spot of the W group	0.5067	0.5609
The preceding spot of the E group	0.5867	0.4618
The following spot of the E group	0.6067	0

The heliocentric coordinates of the sunspots are found as given in Table 1. Then the inclination of the axis of sunspot groups are:

The W group on 23 November $= \dfrac{0.97}{1.47} = 0.66$

The W group on 27 November $= \dfrac{2.36}{2.45} = 0.96$

The E group on 23 November $= \dfrac{0.63}{1.39} = 0.45$

The E group on 27 November $= \dfrac{0.80}{1.27} = 0.63$