Physics. — *Solar flares and the origin of Cosmic Radiation.* I. By J. CLAY, H. F. JONGEN and A. J. DIJKER. (Natuurkundig Laboratorium University of Amsterdam.)

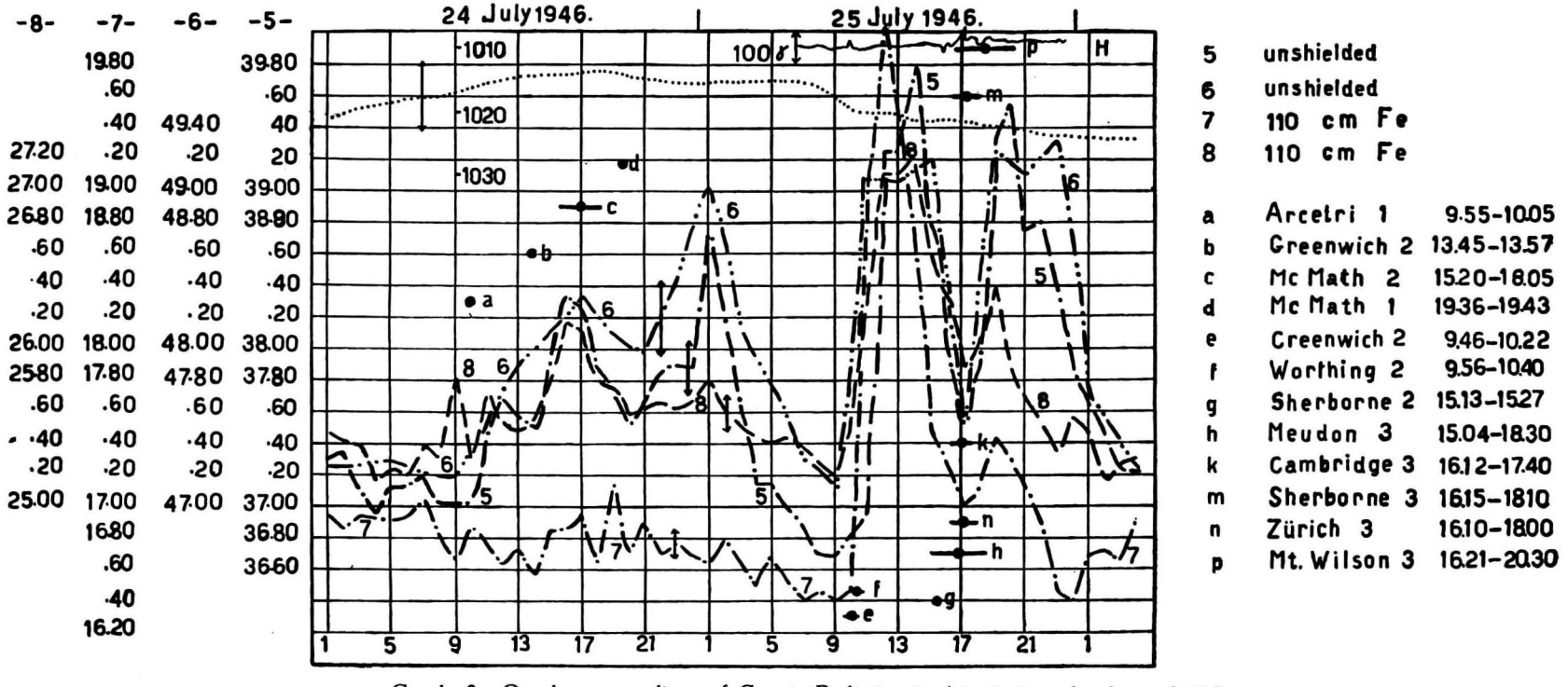
(Communicated at the meeting of September 24, 1949.)

On July 25, 1946 a considerable increase of cosmic radiation was measured at different places of the earth [1, 2]). This was also the case in Amsterdam where for the last 15 years the radiation has been continuously recorded with four ionisation vessels of 40 L each, filled with argon of pressure of 40, 40, 97 and 58 atmosphere resp. The hour-values of the recordings have an accuracy of 0.2 %. One vessel is unshielded (6), one has generally a shield of 12 cm (on the 25th the shield was absent), the remaining two have a shield of 110 cm Fe. In the graph 1 we see the 3 hour-values of these ionisation-vessels. The barometer-curve is given below in millibars, the variation with barometric pressure is from 1.7 % per cm Hg (under 110 cm Fe) to 3 % per cm Hg (open). In the middle of graph 1 the horizontal component of the earth's magnetic field is given in γ units and the variation of 100 γ is indicated by the arrow.

VALLARTA has expounded that the increase of the cosmic radiation might be caused by a magnetic dipole-field of two sunspots, which would compensate the sun's magnetic field, so that at that moment electrically charged particles would be able to escape from the sun, which they could not do as long as these sun spots did not occur. However, we have some doubt as to the validity of this explanation.

In the graph 1 we see an increase of the intensity in the four apparatus between 10 and 15 h. G.M.T. on the 25th of July, but then on July 26 a heavy magnetic storm sets in and in all four vessels a decrease of intensity is recorded, as is usual in the event of magnetic storms. We may mention that on July 25 at 10 a little peak is found in the horizontal component of the geomagnetic field. We have noticed that this is a characteristic feature in practically all the cases where solar flares are accompanied by an increase of cosmic radiation.

We next took the hour-values in stead of the 3-hour values and proceeded to a closer examination of the increases. We found that in the more precise data the variations showed much more plainly and were found to occur as in graph 2. Moreover we detected maxima on the 24th of July, a day of uncommonly heavy activity on the sun, apparently from a great number of solar flares, observed at different stations. The flares are indicated in graph 2 by *a*—*p*. The name of the observatory [3]), the duration and the class of the flares are given in the right-hand part of the graph. For classification of intensity the numbers 1, 2 and 3 are used. Especially the flares *h* till *p* inclusive were of high intensity.



5	unshielded	
6	unshielded	
7	110 cm Fe	
8	110 cm Fe	
a	Arcetri 1	9.55–10.05
b	Greenwich 2	13.45–13.57
c	Mc Math 2	15.20–18.05
d	Mc Math 1	19.36–19.43
e	Greenwich 2	9.46–10.22
f	Worthing 2	9.56–10.40
g	Sherborne 2	15.13–15.27
h	Meudon 3	15.04–18.30
k	Cambridge 3	16.12–17.40
m	Sherborne 3	16.15–18.10
n	Zürich 3	16.10–18.00
p	Mt. Wilson 3	16.21–20.30

Graph. 2. One hour recordings of Cosmic Radiation in 4 ionisation chambers of 40 L, on July 24 and 25, 1946 with solar flares observed at different stations. Barometer.

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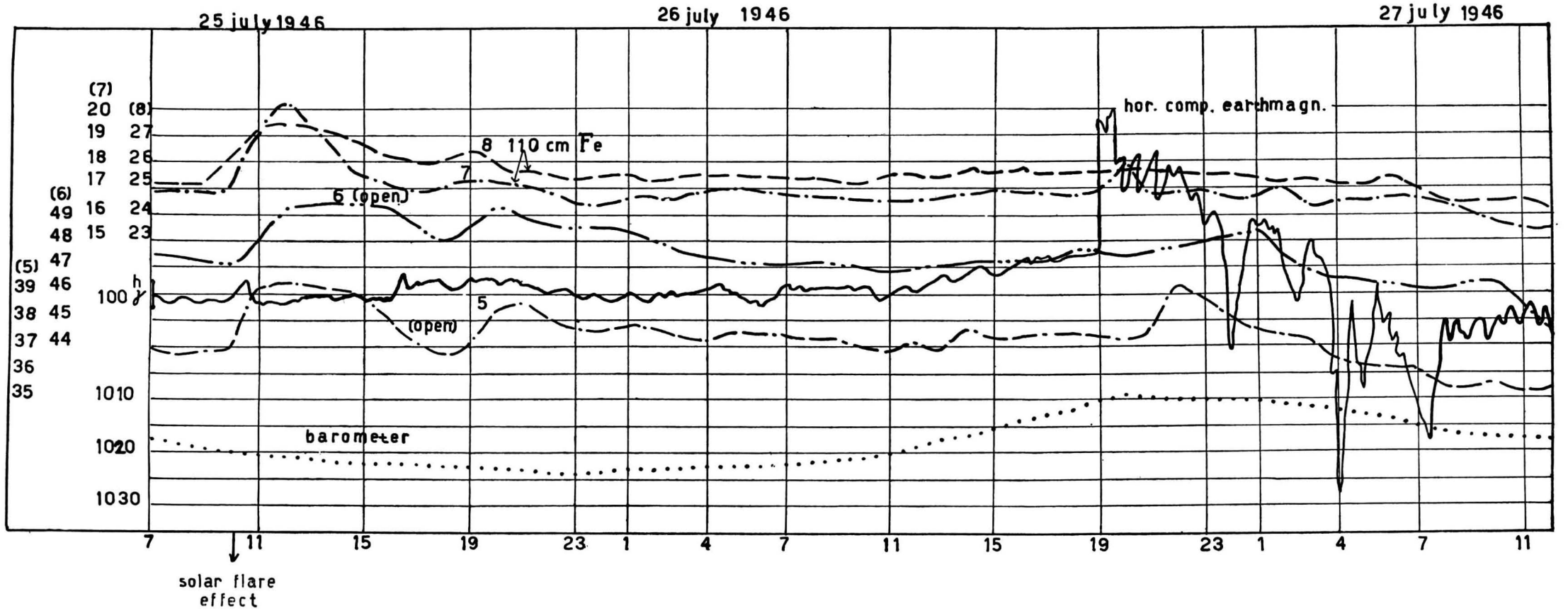

Graph. 1. Recording of 3 hours mean Cosmic Radiation with 4 ionisation chambers of 40 L argon at high pressure. Increase on July 25, 1946, during solar flares, decrease on July 27 during magnetic storm. Barometer.

The relative values of the ionisation currents are given at left expressed in compensation-voltage.

After scrutinizing this detailed result we looked for more cases, starting with the year 1947, which was in part of great solar activity. In this year alone we found more than 30 cases of considerable increased radiation and still 30 more of smaller value all correlated with solar flares. In most cases the shift in the maximum occurred up to 2 hours after the flare was observed.

The magnetic curve does not show variations worth mentioning in this period. But sometimes a small peak arises in the horizontal component a short moment before the beginning of the increase.

We took 7 particular cases with increases of 3—5 % of the radiation and we noted the moment of the observation of the flare and the station where it was observed. Then we looked for sun spots which might be correlated with the flares, considering their place and history, which are given in the text below [4, 5]).

The magnetic moment of the spot is calculated from its surface and the maximum value of the magnetic field within it (in the way suggested by BROXON [6]). The magnetic moments are given in the graphs 3—8. The earth's magnetic field is given in the graph for June 17 1947. We see that the computed magnetic moments of the sunspots differ by a factor of 10^{-4} till 10^{-5} from the formerly accepted total magnetic moment of the sun, which was assumed to be 10^{34} Gauss cm^3.

It is possible that the magnetic fields of these spots are important or indispensible to the phenomenon treated above, but our knowledge on the subject is very fragmentary as yet.

A short time ago a publication by C. E. R. BRUCE [7]) and one by M. A. ELLISON [8]) treated of the possibly considerable magnetic field of the flares. In the graphs below the positive variation of the radiation is given together with the time of observation of the flares. In most cases the maximum of the radiation arose with a retardation of 0—2 hours.

The magnetic dipole momenta are calculated with the formula $M = 0.177a^3 H$, given by BROXON [6]) in his recent paper on this subject in the Physical Review, 1949.

a is the radius of the sunspot which we take as circular and H is the maximum value of the magnetic field which is measured in the center of the spot

May 21, 1947	spot number 8566	$M = 4{,}2 \times 10^{29}$ G cm^3
June 17, 1947	spot number 8626	$M = 9.4 \times 10^{28}$ G cm^3
July 14, 1947	spot number 8709	$M = 1.5 \times 10^{29}$ G cm^3
July 24, 1947	spot number 8715	$M = 4.3 \times 10^{30}$ G cm^3
Aug. 11, 1947	spot number 8764	$M = 1.1 \times 10^{30}$ G cm^3
Aug. 15, 1947	spot number 8775	$M = 5.5 \times 10^{28}$ G cm^3

The flares on July 25 1946 were at a latitude of +23° North. In this point particles of 10^{10} eV cannot escape from the sun [1]).

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[1]) Northern latitude is positive. Difference in longitude is positive towards the west.

May 21, 1947.

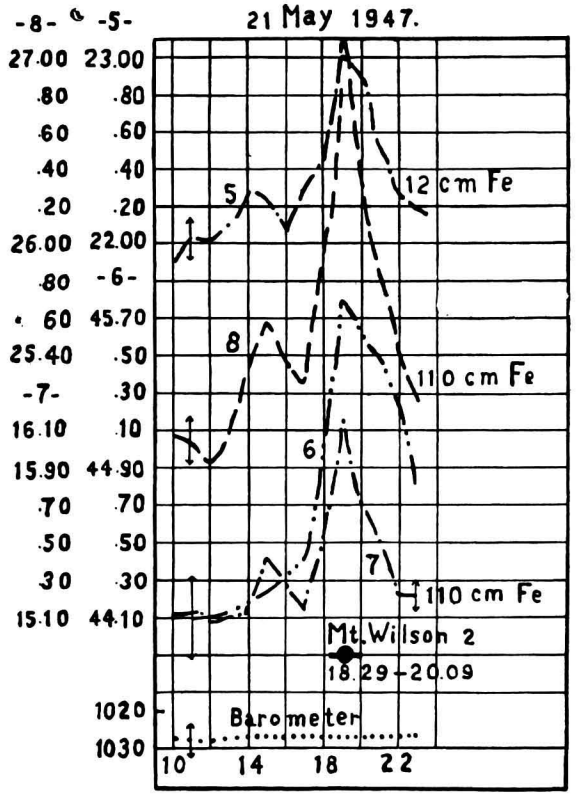
Inset of the increase of intensity in Cosmic Radiation after 18 h. with maximum at about 19 h. Observed solarflare class 2 on Mount Wilson between 18.29 and 20.08 with the maximum 18 h. 44.

The situation of the flare was latitude +20° and the distance till the central meridian —25°.

On this day in the surroundings of the solarflare we mentioned 2 sunspots were observed, 8568 and 8571, with a bipolar magnetic character. The spots are found from 16—29 resp. from. 17—29 May, 1947. Because the spot 8568 is the most likely cause of the effect, we give its history below:

Data	Diff. of latitude to the central meridian	Longitude	Latitude	Surface in 10^{-6} of the sunsurf.	Number of smaller parts
May 16, 1947	— 87°	195°	+ 17°	97	1
	— 87°	195°	+ 19°	48	1
May 17, 1947	— 75°	194°	+ 18°	87	6
May 18, 1947	— 65°	190°	+ 19°	194	3
	— 61°	194°	+ 15°	436	5
	— 58°	197°	+ 17°	727	14
May 19, 1947	— 51°	191°	+ 19°	194	14
	— 45°	197°	+ 17°	1067	27
	— 40°	202°	+ 16°	145	9
May 20, 1947	— 19°	190°	+ 20°	170	20
	— 33°	196°	+ 17°	1018	22
	— 27°	202°	+ 17°	48	10
May 21, 1947	— 27°	188°	+ 20°	194	8
	— 20°	195°	+ 19°	630	19
	— 17°	198°	+ 17°	194	13
May 22, 1947	— 11°	191°	+ 18°	97	10
	— 5°	197°	+ 18°	697	32
	0°	202°	+ 17°	121	12
May 23, 1947	0°	189°	+ 18°	194	12
	+ 7°	196°	+ 17°	582	26
	+ 12°	201°	+ 17°	242	14
May 24, 1947	+ 13°	189°	+ 18°	145	15
	+ 20°	196°	+ 17°	533	28
	+ 26°	202°	+ 17°	242	15
May 25, 1947	+ 25°	188°	+ 19°	145	30
	+ 32°	195°	+ 18°	436	50
	+ 38°	201°	+ 18°	170	31
May 26, 1947	+ 48°	197°	+ 18°	485	13
May 27, 1947	+ 56°	192°	+ 21°	48	3
	+ 60°	196°	+ 18°	533	12
	+ 66°	202°	+ 17°	24	5
May 28, 1947	+ 76°	199°	+ 16°	436	4
May 29, 1947	+ 88°	198°	+ 16°	145	2

On May 29, this spot dissappears from the visible region on the west side. The underlined part of the spot was about in the same place as the flare the number of separate spots having diminished from 20 to 8.



Graph. 3. One hour recordings of Cosmic Radiation. Solar flare. Magnetic moment of sunspot on May 21, 1947. Barometer.

June 17.

The increase of cosmic radiation is observed after 9 h. with a maximum at about 11 h. At this time there are the following flares

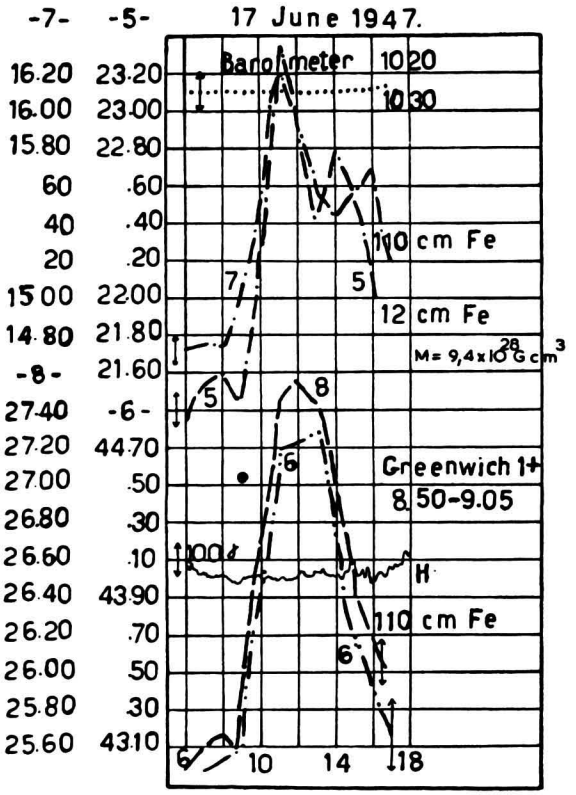
Observation place	Beginning	End	Latitude	Diff. of longitude	Class
Zürich	7 h. 20	7 h. 25	+ 23°	— 52°	point brillant
Wendelstein	8 h. 50		+ 8°	— 9°	1
Greenwich	8 h. 50	9 h. 05	+ 8°	0°	1+

On this day at the latitude of 8° an active region was observed with a longitude of 220° on account of this localisation.

We came to the conclusion that the spot 8626 which is of a bipolar character with a maximum field of 2500 Gausz at 12 o'clock can be the origin of this flare. This spot exists from 12 till 23 June. Here is its history.

8626

Data	Diff. of longitude	Longitude	Latitude	Surface in 10^{-6} of the sunsurf.	Number of smaller parts
June 12, 1947	— 67°	217°	+ 9°	48	4
June 13, 1947	— 51°	219°	+ 9°	97	4
	— 47°	223°	+ 9°	61	1
June 14, 1947	— 37°	221°	+ 8°	73	9
	— 33°	225°	+ 7°	61	1
June 15, 1947	— 25°	220°	+ 8°	24	3
	— 18°	227°	+ 7°	61	2
June 16, 1947	— 12°	220°	+ 9°	36	4
	— 3°	229°	+ 7°	73	1
June 17, 1947	+ 1°	219°	+ 8°	24	9
	+ 9°	227°	+ 7°	48	1
June 18, 1947	+ 15°	220°	+ 10°	73	6
June 19, 1947	+ 28°	220°	+ 9°	73	9
June 20, 1947	+ 40°	219°	+ 9°	218	10
June 21, 1947	+ 54°	219°	+ 9°	291	8
June 22, 1947	+ 65°	217°	+ 10°	194	1
	+ 73°	225°	+ 10°	145	1
June 23, 1947	+ 78°	217°	+ 10°	145	1



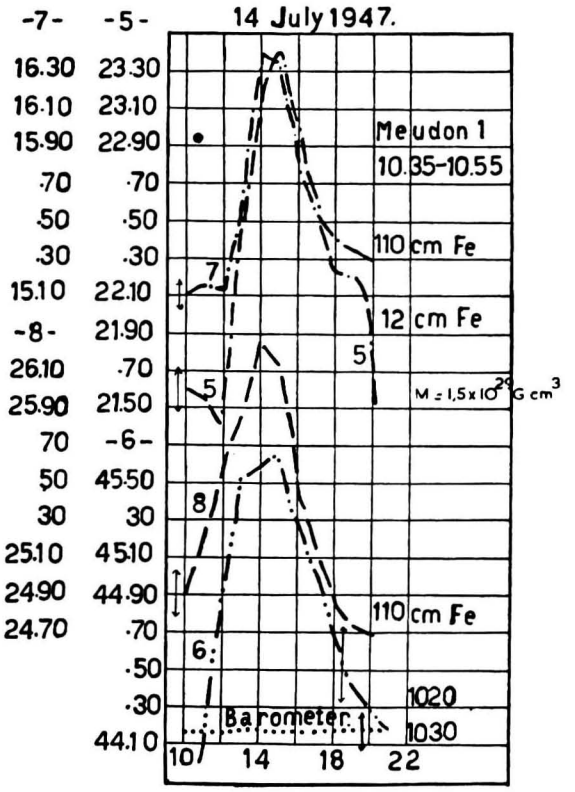
Graph. 4. One hour recordings of Cosmic Radiation. Solar flare and magnetic moment on June 17, 1947. Record of horizontal component of earth's magnetism on that date. Barometer.

July 14.

The increase of intensity of the cosmic radiation begins between 11 and 12 o'clock and the maximum is at about 15 h.

Observed solar flare at Meudon from 10.35—10.55 with a latitude of 13°. In this place on July 14 a spot 8709 is found. The group is unipolar and is followed by a bipolar group. Max. field value H = 1100 Gausz on July 19 at 2000 G.C.T.

8709. Data	Diff. of longitude	Longitude	Latitude	Surface in 10^{-6} of the sunsurf.	Number of smaller parts
July 12, 1947	— 87°	160°	+ 12°	48	1
July 13, 1947	— 74°	160°	+ 12°	194	1
July 14, 1947	— 60°	160°	+ 12°	170	2
July 15, 1947	— 46°	160°	+ 12°	121	5
July 16, 1947	— 32°	162°	+ 12°	73	5
July 17, 1947	— 19°	162°	+ 13°	73	4
July 18, 1947	— 5°	163°	+ 9°	24	2
	— 5°	163°	+ 14°	61	2
July 19, 1947	— 7°	161°	+ 13°	97	4
July 20, 1947	+ 20°	162°	+ 13°	48	2
July 21, 1947	+ 32°	161°	+ 13°	36	1
July 22, 1947	+ 47°	161°	+ 13°	12	2



Graph. 5. One hour recordings of Cosmic Radiation. Solar flare and magnetic moment on July 14, 1947. Barometer.