National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-12487

ST - SP - 10594

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(USSR)

FACILITY FORM 602

N67-26410 (ACCESSION NUMBER)

(THRU)

106 (PAGES)

5 (CODE)

CR 84096 (NASA CR OR TMX OR AD NUMBER)

29 (CATEGORY)

27 APRIL 1967

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Vestnik Leningradskogo Universiteta
Matematika, Mekhanika, Astronomiya
No.1, vypusk 1, 133 - 136,
Izdatel'stvo "LGU", 1967

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SUMMARY

The forbidden lines of OI (λ5577.3 A, λ 6300.3 A, λ 6363.8 A) and SI (λ 4589.29 A) in the spectrum of three sunspots are the object of study. The line λ 4589.29 A in the spectrum of the Sun is identified by the author as the forbidden line SI. This study indicates that the line λ 5577.3 A is attenuated in the spectrum of the spot, whereas the lines λ 6300.3 A, λ 6363.8A and λ 4589.3 A are enhanced.

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1. The transitions between the ground state $np^4\,{}^3P_{210}$ and the metastable states $np^4\,{}^1D_2$ and $np^4\,{}^1S_0$ provide in case of LS-coupling electrically-quadupole emission. But in case of deflection from the LS-coupling, which takes place to a greater or lesser degree in atoms with various np^4-configurations, there is emitted also a magneto-dipole radiation. The probability of transition for the latter is much greater (of the order 10^3) than for the former. This is why at transitions ${}^3P_{21}$ — ${}^1D_2$ and ${}^3P_1$ — ${}^1S_0$ the emission has a magneto-dipole character (Fig.1). A purely electrically-quadrupole radiation is emitted at transition between the metastable states $np^4\,{}^1D_2$ and $np^4\,{}^1S_0$. The probability of the considered transitions is nevertheless still small by comparison with the allowed transitions, for they are forbidden by the respective rules of selection. Despite this, there are observed in astronomical objects and in specific laboratory conditions lines of emission corresponding to these transitions.

As is well known, the forbidden lines OI λ 6300.3Å ($2p^4\,{}^3P_2 - 2p^4\,{}^1D_2$), λ 6363.8 Å ($2p^4\,{}^3P_1 - 2p^4\,{}^1D_2$) and λ 5577.3Å ($2p^4\,{}^1D_2 - 2p^4\,{}^1S_0$) have been observed in spectra of nebulae and polar aurorae. The line λ 6300.3A is three times more intensive than the line λ 6363.8 A. The same correlation is obtained by theoretical calculations of probabilities of transitions. The line λ 5577.3 A has a probability of transition 280 times greater than the line λ 6300.3 A.

(*) /SAPRESHCHENNYYE LINII OI AND SI V SPEKTRE SOLNECHNYKH PYATEN/

The observed relative intensity of these two lines is essentially different for various sources. This is explained by the fact that the relative intensity depends not only on the transition probability, but also on the relative number of atoms populating the levels. This last case is dependent on gas temperature and density.

A large number of published works have been devoted to the study of the forbidden lines of oxygen (see bibliography of ref.[1]). In the aurora spectrum the line λ 5577.3 A is many times more intense than the line λ 6300. 3 A. But in the spectrum of gas nebulae the lines λ 6300.3 A and λ 6363.8 A are sharply outlined. At the same time they have quite different intensities for various sources [2].

Three weak absorption lines were identified by Bowen in the spectrum of the Sun [3], Cabannes and Dufay [4] as the forbidden lines OI corresponding to transitions $^3P_{21} - {}^1D_2$ and $^1D_2 - {}^1S_0$. Bowen utilized these lines for the determination of oxygen abundance on the Sun and obtained satisfactory results.

There appeared relatively recently a communique [5] on the observation of forbidden lines SI in the discharge tube spectrum. The line corresponding to the forbidden transition $^3P_1 - {}^1S_0$ has a wavelength equal to λ 4589.21±0.05 A. the wavelength of the line corresponding to the transition $^3P_2 - {}^1S_0$, was measured with less precision, for it was concealed by the molecular band of sulphur. Note that the transition probability for the line $^3P_2 - {}^1S_0$ is 20 times smaller than for $^3P_1 - {}^1S_0$. The weak absorption line λ 4589.29 A in the Sun's spectrum was identified by us with the forbidden line SI λ 4589.21 A [6].

The study of forbidden lines OI and SI in the spectrum of sunspots offers great interest.

2. We utilized as spectral observation material for sunspots the spectrograms obtained in 1957 and 1959 by S. S. Zhuravlev and in 1965 by the present author in the solar telescope with an AOLGU* autocollimation spectrograph. The spectrgrams' negatives were obtained in the second order diffraction spectrum (the dispersion being ≈ 1 mm/A).

The data on the sunspots observed are compiled in Table 1 hereafter, where the coordinates of the group (ϕ, λ), in which the observed spot was located are in the second column, and the area of the observed spot in ppm in the third column, the fourth one showing the intensity of the magnetic field.

TABLE 1

Observation Date	coordinates ϕ	coordinates λ	Sp ****	H, gauss
26 VI—27 VI 1957	−20.5	141.5	1280	4000
19 VI—21 VI 1959	− 9.0	288.5	1100	3700
9 IX—11 IX 1965	+26.5	185.0	155	2000

* Astronomical Observatory of the Leningrad State University. ** according to "Solar Data". *** determined by line λ 6302.5A FeI splitting.**** ppm of hemisphere.

The investigation was conducted spectrometrically as well as spectrophotometrically. The relative measurements of spectral lines' wavelengths in the nucleus and in the spot penumbra, and also in the unperturbed photosphere near it, were conducted on the IZA-2 measurement device. The registrograms of spectral lines were obtained by means of a recording microphotometer of the Mohl (?) system.

It follows from the measurements of Evershed effect in forbidden lines OI and Si in sunspot spectrum of 27 June 1957 and 19 June 1959 that the lines are displaced by radial outflow of matter of the spot's nucleus. This displacement is in complete accord with the shift shown by lines of metals. The line λ 6300.3 A, measured relative to telluric lines λ 6302.000 A and λ 6298.457 A in the nucleus of the 1959 spot shows a displacement toward the violet end of the spectrum, equal to about 0.030 ± 0.005 A. An identical shift is obtained by the lines FeI λ 6297.799 A and λ 6301.508 A.

As to the spectrum of 1957 and 1965 spots' nucleus, the line λ 6300.3 A shows no measurable displacement. But the line λ 5577.3 A, measured relative to solar lines λ 5576.096 A FeI and λ 5581.979 A CaI, shows in the nucleus of 1957 and 1959 spots a shift into the longwave end of the spectrum. It is equal to 0.025 ± 0.005 A. -- The lines λ6363.8 A [OI] and λ 4589.3 A (SI) in the nucleus of the spot do not indicate any substantial displacements.

TABLE 2

λ, A	λ_{meas}, A	Transition	Excitation potentials, ev		$\bar{W}$, m A	
			lower	upper	photosphere	spot's nucleus
5577.34 [OI]	5577.350±0.005	$2p^4\,{}^1D_2 - 2p^4\,{}^1S_0$	1.96	4.17	6±1	2±1
6300.32 [OI]	6300.325	$2p^4\,{}^3P_2 - 2p^4\,{}^1D_2$	0.00	1.96	5	15
6363.79 [OI]	6363.810	$2p^4\,{}^3P_1 - 2p^4\,{}^1D_2$	0.02	1.96	3	10
4589.29 [SI]	4589.290	$3p^4\,{}^3P_1 - 3p^4\,{}^1S_0$	0.05	2.74	3	10

Compiled in Table 2 are the results of measurements of wavelengths and of equivalent widths: shown in the first column are the wavelengths of the lines [OI] and [SI] according to the Utrecht catalog [7], in the second column — the wavelengths measured by the author at the center of the Sun's disk, in the third — the transition corresponding to the given line, in the fourth and in the fifth — the excitation potentials of the lower and upper levels.

Photometry of the indicated lines shows that during transition from photosphere to the nucleus of the spot they vary differently. The line λ 5577.3 A attenuates, and the lines λ 6300. 3 A and λ 6363.8 A are enhanced.

In the spectra of the large spots of 1957 and 1959 the line λ 5577.3 A is weakened by intensity three times, and the lines λ 6300. 3 A, λ 6363.8 A and λ 4889.3 A are enhanced just about as many times by comparison with their photospheric intensities. The mean equivalent widths of these lines in spectra of the center of Sun's disk and the spot nuclei of 1957 are brought out in the sixth and seventh columns of Table 2. The difference between the values

of $\bar{W}$ for 1957 and 1959 is within the measurement errors. It should be noted that the line λ 6363.8 A in the spot is probably somewhat overrated in intensity; this is due to merging.

We reproduced in Fig.2 the spectrum portion of the 1957 spot's nucleus with the lines considered. It may be seen from it that the lines λ 6363.8 A and λ 4589. 3 A show a tendency to splitting.

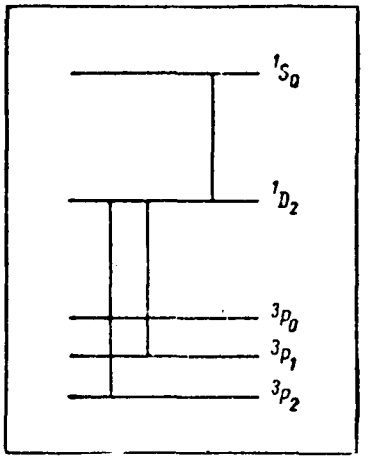

Fig.1. Ground and metastable levels of the np^4-configuration and the transitions between them

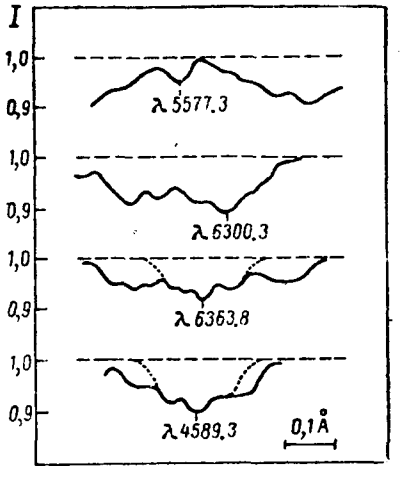

Fig.2. Portions of the spectrum of the sunspot with the lines [OI] λ 5577.3 A, λ 6300. .3 A. λ 6363.8 A and [SI] 4589.3 A. The dotted line indicates the assumed contour of lines λ 6363.8 A, λ 4589.3 A.

The observations of 1965 point to the fact that the intensity variation of the lines considered at transition from the photosphere to the nucleus of the spot is hardly noticeable. We should also note that the 1965 spot's dimensions are smaller than those of 1957 and 1959 sunspots. It follows from the above that the intensities of the lines depend on the physical conditions of the medium where they arise.

3. The observed difference between the intensities of the line λ 5577.3A in the spot and in the photosphere is apparently caused by the difference in the number of atoms in the excited state $2p^4\,{}^1D_2$ (the number of excited atoms in the spot is three times less than in the photosphere). On the other hand, as pointed out at the beginning of this paper, the intensities of the lines λ 5577.3 A and λ 6300.3 A are different in gas nebulae and polar aurorae. This is explained by the fact that the density of the matter is different in these objects. The lower the density, the greater the intensity of lines λ 6300.3 A and λ 6363.8 A relative to the line λ 5577.3 A. Apparently an analogous phenomenon takes place in the given case.

The excitation of the atom may take place in two ways: 1) under the action of radiation, that is, by way of light quantum absorption and 2) under the action of collisions (impacts of first kind). The first process leads to

to the formation of the line of absorption. In spots both the total and the electron pressures are low by comparison with the photosphere. Therefore, the excitation under the action of collisions is less intense in spots than in the photosphere. This probably leads to enhancement of forbidden lines λ 6300.3 A [OI], λ 6363.8 A (OI] and λ 4589.3 A [SI] during the transition from photosphere to spot.

The author conveys his gratitude to Prof. O. A. Mel'nikov for valuable comments and remarks.

*** THE END ***

Manuscript received on 31 May 1966

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CONTRACT No.NAS-5-12487
VOLT TECHNICAL CORPORATION
1145 19th St.NW
WASHINGTON D. C. 20036

Translated by ANDRE L. BRICHANT

on 26-27 April 1967

DISTRIBUTION

611 (6), 612 (6), 613 (10), 614 (10), 615 (6), 640 (8) Hq. add ROMAN, GLASER(SG) rest as usual.