ASTRONOMY

1962

SovietRxiv

Abstract

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ASTRONOMY

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RESONANCE LINES 304 Å HeII AND 584 Å HeI ON THE SUN

(Presented by Academician V. G. Fesenkov, July 4, 1962)

Beginning in 1958, when the 304 Å HeII and 584 Å HeI lines were photographically recorded by Violet and Rense (^1) with the aid of a spectrograph carried on a rocket, observations of \$ \$304 Å and \$ \$584 Å have been carried out repeatedly (^{2}-6). The lines \$ \$304 Å and \$ \$584 Å possess a number of special features: they belong to an element of high cosmic abundance, and their excitation potential is close to the ionization potential.

At present, in accordance with experiment, it is accepted that the radiation flux from the entire Sun near the Earth is equal to: for \$ \$304 Å, ~ 0.3 erg/cm$^2 \cdot$ sec; for \$ \$584 Å, ~ 0.03 erg/cm$^2 \cdot$ sec. A prediction of the intensities of solar emission lines in $\lambda = 19$-2800 Å (^7) made it possible to identify most of the observed lines in the spectral region $\lambda \leqslant 1100$ Å (^8). The principal result of the latter work is the conclusion that the observed line intensities in $\lambda = 200$-500 Å are underestimated by approximately one order of magnitude. According to (^8), $F_{304}/F_{584} \simeq 20$-30, and not 10, as follows from observations. In this connection, a determination of the intensity of solar radiation in \$ \$304 Å and \$ \$584 Å is highly desirable. On the other hand, the question of the formation of helium lines in the solar atmosphere is of independent interest. At present nothing is known about the distribution of \$ \$304 Å and \$ \$584 Å radiation over the disk of the Sun, or about the heights of formation of these lines in the solar atmosphere.

In works (^{9},10), on the basis of a study of rocket data on solar radiation in the far ultraviolet, of materials obtained during solar eclipses, and also of data on the thermal radio emission of the Sun in the range 1-30 cm, a model was constructed of the active and undisturbed regions of the solar atmosphere. This model includes the distribution with height h of the electron temperature T_e and concentration n_e, the concentration of neutral and ionized helium $n_{\mathrm{He\,I}}, n_{\mathrm{He\,II}}, n_{\mathrm{He\,III}}$. We shall use the data of (^{9},10) in what follows.

1. **The He II line** $1s^2S$—$2p^2P^0$ 303.8 Å. Excitation of the initial level 2^2P^0 is due to: 1) electron impacts acting on the ground level, and 2) photorecombinations. The principal processes by which atoms leave the 2^2P^0 level are spontaneous transitions.

Fig. 1. HeII, $\lambda 304$ Å. 1—active regions, 2—quiet regions; a—recombinations, b—electron impacts

Figure 1: Fig. 1. HeII, $\lambda 304$ Å. 1—active regions, 2—quiet regions; a—recombinations, b—electron impacts

It is not difficult to show that, under the conditions of the solar atmosphere, only these processes are significant and practically all helium atoms are in the ground state. Then the number of \$ \$304 Å quanta formed in 1 cm^3 in 1 sec is

$$n'_{\mathrm{He\,II}} A_{21} = n_{\mathrm{He\,II}} n_e W_{12} + n_{\mathrm{He\,III}} n_e \sum R. \tag{1}$$

The coefficient of excitation by electron impact, according to ($\frown$11), is

$$W_{12} = \frac{10 f}{T_e^{3/2}} \left[\frac{e^{-x}}{x} - \mathrm{Ei}(x) \right], \tag{2}$$

where, for HeII $\lambda 304$ Å, $f = 0.42$ is the oscillator strength, and $x = 4.74 \cdot 10^5 / T_e$; $\mathrm{Ei}(x)$ is the exponential-integral function.

The recombination excitation of $\lambda 304$ Å will occur through photorecombinations to all levels with principal quantum number $m \geqslant 2$, except for the mp terms, since the latter combine with the ground level 1^2S, bypassing the state 2^2P^0. Taking into account the statistical weight of the various terms, for the recombination coefficient in (1) one obtains the estimate

$$\sum R \approx \left[\frac{2}{3} \sum_{m=2} R_m + \frac{1}{3} R_2 \right], \tag{3}$$

where R_m is the Menzel recombination coefficient for a hydrogen-like ion [12]

$$R_m = 3.2 \cdot 10^{-6} m^{-3} Z^4 T_e^{-3/2} e^x \, \mathrm{Ei}(x). \tag{4}$$

The sum of recombinations, according to [11],

$$\sum_{m=2} R_m = \frac{1.6 \cdot 10^{-6} Z^4}{x T_e^{3/2}} \left[e^{x_1} \, \mathrm{Ei}(x_1) + \ln(1.8 x_1) \right], \quad x_1 = \left(\frac{m_1}{m_1 + 1/2} \right)^2 x = \frac{4}{9} x. \tag{5}$$

Fig. 1. HeII, $\lambda 304$ Å. 1—active regions, 2—quiet regions; *a*—recombinations, *b*—electron impacts

For HeII, $Z = 2, \; x = 6.3 \cdot 10^5 / T_e$.

Using the data [9,10] and expressions (1)–(5), we calculated the distribution of the volume emission of the solar atmosphere in λ304 Å. The results are presented in Fig. 1. The areas under the curves in Fig. 1 give the radiation of an elementary column of the solar atmosphere (quanta/cm^2·sec.) in all directions.

Thus, active regions on the Sun in the λ304 Å line turn out to be 6 times brighter than quiet regions. If the area of helium flocculi is taken as $S = 0.3$ (active Sun), then the radiation flux in λ304 Å from the whole Sun is 0.9 erg/cm^2 · sec.* In this case, 0.7 of all the λ304 Å radiation comes from active regions. It follows from this that, with the solar-activity cycle, λ304 Å should vary by a factor of 2–3.

We assumed the solar atmosphere to be transparent for λ304 Å. In work [11] it was shown that, despite a considerable optical thickness τ in resonance lines caused by scattering, the radiation may be regarded as "optically thin" as long as true absorption of quanta is not substantial. The condition for the absence of the latter [11] is

$$\tau < \tau_0 = (A_{21}/n_{eB_{21}})^{1/2}, \tag{6}$$

where B_{21} is the coefficient for quenching of the excited state by electron impact. In our case condition (6) is satisfied ($10^2 < 10^4$). In the lower layers of the solar atmosphere the λ304 Å radiation will be "optically thick" ; however, as calculations show, because of the low temperature T_e this radiation is negligibly small.

In the region of formation of λ304 Å, $T_e \sim 10^{5\circ}$, and therefore the line width, determined by the Doppler effect, is 0.04 Å.

* This value agrees well with that obtained by us earlier [11] by reducing the results of [1] for atmospheric absorption (1.2 erg/cm^2 · sec.).

Recently, on 7 March 1962, the OSO ("Orbiting Solar Observatory") satellite was launched in the USA with a spectrophotometer continuously recording the solar spectrum at λ10–400 Å. A preliminary report[(13)] at the Third COSPAR Symposium contains the results of measurements of three lines during a chromospheric flare on 13 March 1962, 15h U.T., of class 1+—2+. According to[(13)], with the appearance of the flare the flux from the whole Sun at λ304 Å increased by 10% and remained so, at least, throughout its entire duration ($\sim 2 \cdot 10^3$ sec). The area of the flare was $\sim 2 \cdot 10^{-3}\odot$, and the flux emitted by it at λ304 Å is equal to $0.9 \cdot 10\% \simeq 0.1$ erg/cm^2·sec; therefore the surface brightness of the flare is approximately 10 times greater than the brightness of the active region where flares usually occur. The enhancement of λ304 Å may be associated with an increase in the density of matter in the flare region by a factor of 3–4, or with a rise in temperature. A sudden increase in density seems unlikely to us. Since the probability of excitation by electron impact depends exponentially on T_e with an exponent $\sim 5 \div 6$, an increase of T_e by a factor of 1.5–2 in the

Fig. 2. He I, λ584 Å. The designations are the same as in Fig. 1

Figure 2: Fig. 2. He I, λ584 Å. The designations are the same as in Fig. 1

flare region is sufficient for the intensity of λ304 Å to increase by one order of magnitude.

Fig. 2. He I, λ584 Å. The designations are the same as in Fig. 1.

The estimate of the time required to establish the elevated T_e gives a small value ($\sim$ 10–100 sec). Since the flare flux at λ304 Å is $\simeq 0.1$ erg/cm^2·sec, the total energy emitted by the flare during its lifetime is $\sim 10^{29}$ erg. The total energy of the flare in all short-wavelength lines ($\lambda \leqslant 1000$ Å) is apparently one order of magnitude higher (10^{30} erg). As a result of radiation, the gas in the flare will cool very rapidly; calculations show that its energy will be exhausted in 1 sec. It follows from this that a continuous influx of energy with a power of $\sim$ 0.1–0.01 erg/cm^3·sec is necessary in the flare region. Strictly speaking, this value is a lower limit to the real value. It seems to us that these facts limit the possibility of treating a chromospheric flare as an explosion and are an argument in favor of representing the flare as a region of prolonged energy release.

2. The He I line $1s^{2\,1}S$—$2p^{1\,1}P^0$ **584.3 Å.** As in the case of λ304 Å, the "optically thick" radiation of He I is negligibly small, since it comes from regions with $T_e \simeq 6300°$. This result was obtained by us from condition (6) and the model of the solar atmosphere[9,10]. Consequently, λ584 Å will arise in an optically thin layer, and the flux of quanta will be determined by equation (1). For calculating W one may use expression (2) with $f = 0.36$ and $x = 2.37{\cdot}10^5/T_e$. The recombination coefficient can also be calculated from formula (3); however, a factor 1/4 should be introduced, accounting for the statistical weight of the system of singlet and triplet levels. In this case $x = 2.9 \cdot 10^5/T_e$.

Figure 2 shows the distribution of the volume emission of λ584 Å obtained by us for active and undisturbed regions of the solar atmosphere.

The glow in λ584 Å occurs mainly (80%) due to recombination excitation. The contrast between active and undisturbed regions of the Sun is 3.5. The flux at λ584 Å from the whole Sun near the Earth is ~ 0.03 erg/cm^2·sec. About 1/2 of all the radiation deter-

is determined by active regions; therefore the variations of λ584 Å with the solar-activity cycle should not exceed a factor of 2.

The emission of λ584 Å in a flare, if it is associated with an increase in T_e, should increase only slightly, since recombination depends only weakly on T_e. If the fraction of the λ584 Å emission due to electron impacts increases by one order of magnitude, then the flux from the entire Sun in λ584 Å will increase by 2–3% during a flare of average power.

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Received
28 VI 1962

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Note: Figure translations are in progress. See original paper for figures.