that the noted Indian scientist Meghnad Saha, whose work led to the founding of theoretical astrophysics, was offered the Deputy Director's post at Kodaikanal by the Calcutta-based Director-General of Observatories. For some reason never really explained, Saha turned down the offer[12].

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Saha's proposals for upper-atmospheric studies

S. N. Ghosh

Meghnad Saha was the first to propose the setting up of an upper-air observatory for the study of the characteristic features of solar spectrum in the far- and extreme-ultraviolet regions and their control of upper-atmospheric phenomena.

In a paper, 'On a solar stratospheric observatory', published in 1937 in the bulletin of astrophysical records of Harvard University's observatory[1], Saha visualized the enormous scientific information that could be obtained from such an observatory. 'The observed solar spectrum photographed from altitude above 40 km', he said, 'would then extend deep into the ultraviolet.' This idea is dealt with in detail in two other publications[2, 3] and in Saha's presidential address at the Indian National Institute of Sciences meeting at Lahore in 1938. In these papers, Saha observed:

(i) A satisfactory theory of upper-air phenomena must be based on precise knowledge of the action of ultraviolet sunlight below 3000 Å (300 nm) on O_2 and N_2. Apart from observations from space, well-planned laboratory experiments on the spectra of these absorbing molecules are essential.

(ii) The ultraviolet radiation from the Sun differs widely from that of a black body and in selected wavelength regions the Sun must be emitting nearly a million times more photons than are given out by a black body at 6500 K.

(iii) The ultraviolet spectrum of the Sun consists of a continuous spectrum with superimposed emission lines of H, He, He^+, Fe^+ ions, etc.

Saha made these remarks at a time when ground-based instruments could record the solar spectrum only up to 2900 Å. To prove his predictions, there was a need to carry observing instruments above the Earth's absorbing layer[4]. Unfortunately, during Saha's lifetime, balloons carrying recording instruments could reach only low heights and rocket-borne experiments had only just begun. It was then extremely difficult to know the characteristics of sunlight in the deep-ultraviolet region, and consequently their control of upper-atmospheric phenomena remained unexplored.

Upper-atmospheric studies

Immediately after World War II the study of the upper atmosphere by direct methods was greatly enhanced. Balloons, which could carry recording instruments to low altitudes, were replaced by rockets, which could attain higher altitudes. The disadvantage of the short time of only about 5 minutes between the launch of a rocket and its return to ground, which made the use of sensitive instruments requiring long observation times impossible[5], was overcome by performing experiments in unmanned satellites which stayed aloft for many years. Orbiting space laboratories even permitted prolonged stay in space and facilities to carry out experiments.

In addition to experiments in space, laboratory experiments were carried out. Detailed information on the spectra of absorbing atmospheric atoms and molecules in the ultraviolet was obtained. Over 200 solar emission lines have been detected in the region between 2000 Å and 60 Å (ref. 6; see Figure 1). Most of these lines have been identified with H, He, O, N, C, Si, Ne, S atoms and ions in various states of ionizations. They are produced in the chromosphere and corona.

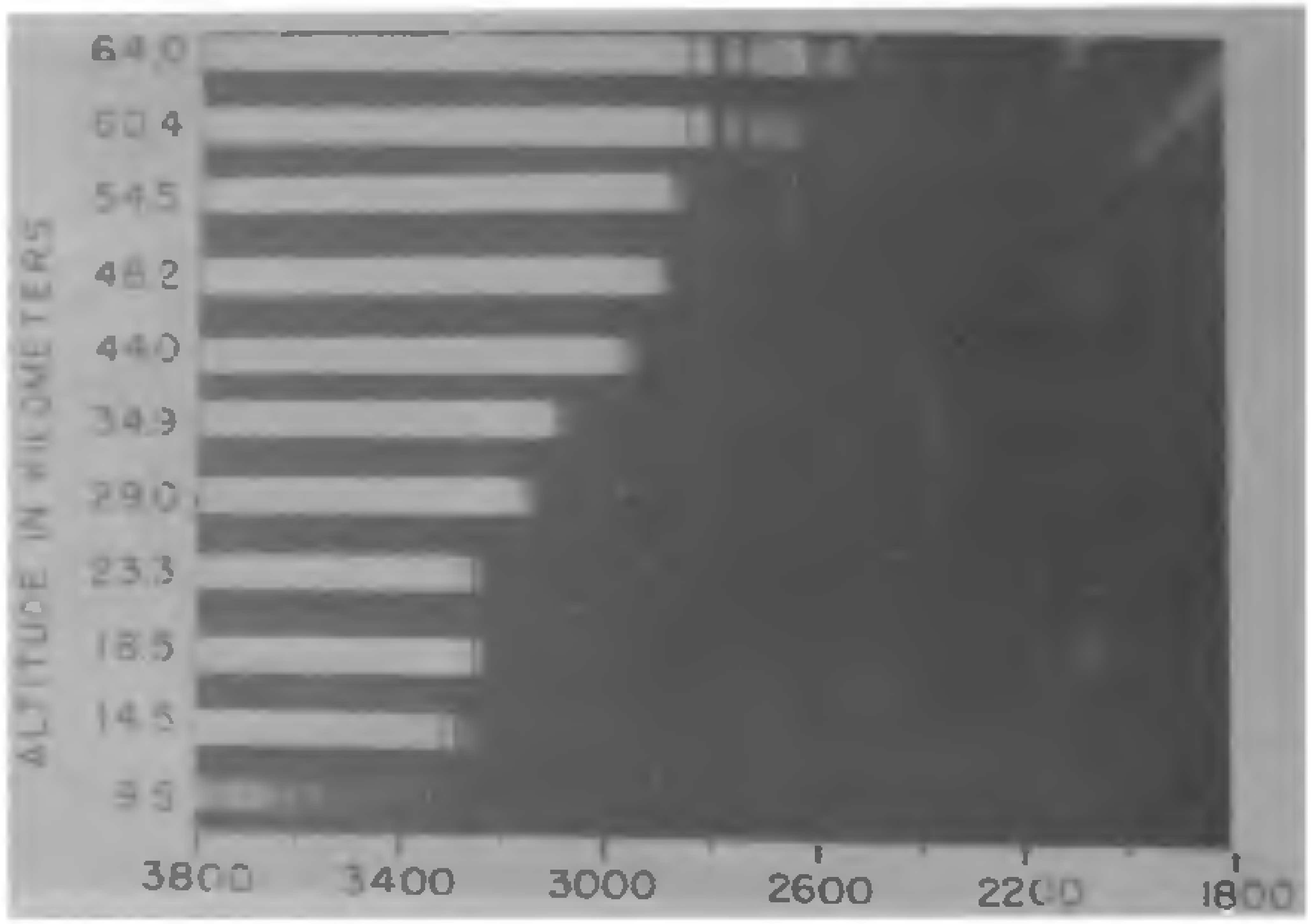

Figure 2. Solar spectra obtained on 14 June 1949 from an Aerobee at different altitudes.

Confirmation of Saha's predictions

As more rockets, satellities and space laboratories took upper-air observations Saha's assertions were confirmed one after another. It was confirmed that solar radiations in the far-ultraviolet spectra of the Sun are effective in producing upper-atmospheric phenomena. Further, it was proved that, if a spectrograph was taken above 40 km, the solar spectrum could be recorded to shorter wavelengths[7] (Figure 2). Saha's prediction of strong emission lines also came true. Resonance lines of neutral atoms HI (1215.7 Å Ly α), HeI (584 Å) and lines of ions HeII (304 Å), Mg X (625 Å) Ne VII (430 Å) O IV (790 Å), O V (630 Å) and N IV (765 Å) Si XII, Fe XV and Fe XVI and others, and continuum of H, He, etc appear in the far-ultraviolet region of the solar spectrum.

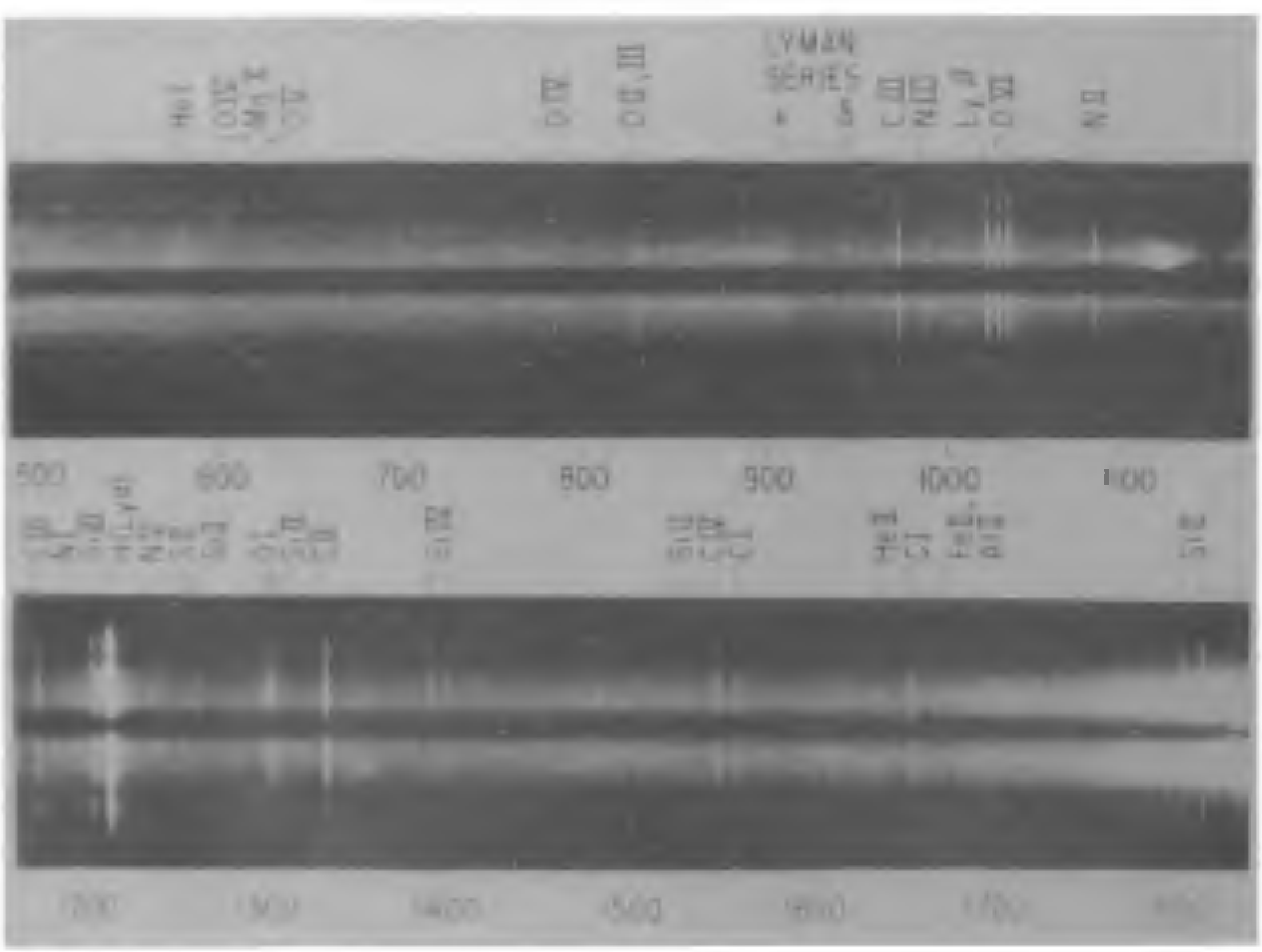

Figure 1. Solar spectrum photographed from a height of 200 km up to HeI resonance line at 584 Å.

Absorption of solar UV light

In the earth's atmosphere, absorption above 2000 Å is principally due to ozone, that between 2000 and 850 Å due to O_2, and that below 850 Å due to all atmospheric constituents. Owing to UV absorption oxygen (O_2) is allotropically modified to ozone (O_3). Various ionized layers, known as D- E- and F-regions constituting the ionosphere, are formed.

Twilight airglow emission

It was observed that many diatomic molecules show feeble or sometimes no absorption to the lowest state of their ions from the ground state of molecules, but exhibit strong absorption to an excited state of the ions. Based on this observation, Saha asserted that night (actually twilight) airglow emission from N_2^+ ions can be accounted by the solar ultraviolet absorption by N_2 molecules in the ground state to the first excited state of N_2^+ ions and subsequent transition to the lowest state of the ions[2] (Figure 3):

$$N_2(X) + h\nu(\lambda < 661 \text{ Å}) \rightarrow N_2^+(A) + e$$

$$N_2^+(A) \rightarrow N_2^+(X) + h\nu.$$

Formation of ionized layers (ionosphere)[8]

D-region	E-region	F-region
(50–90 km) Principally by Lyα 1216 Å ionizing NO and X-rays 1–10 Å; also by electrons > 30 keV, protons 1 keV, cosmic rays.	(90–150 km) 911–1027 Å, principally by Lyβ 1026 Å ionizing O_2 and X-rays 10–170 Å; also by electrons 1–30 keV causing some night-time and sporadic E ionizations.	(150–600 km) 170–911 Å, principally HeII 304 and HeI 584 Å ionizing O_2 ($\lambda < 911$ Å) and N_2 ($\lambda < 790$ Å); also by electrons < 1 keV (may be small; might be significant at night).

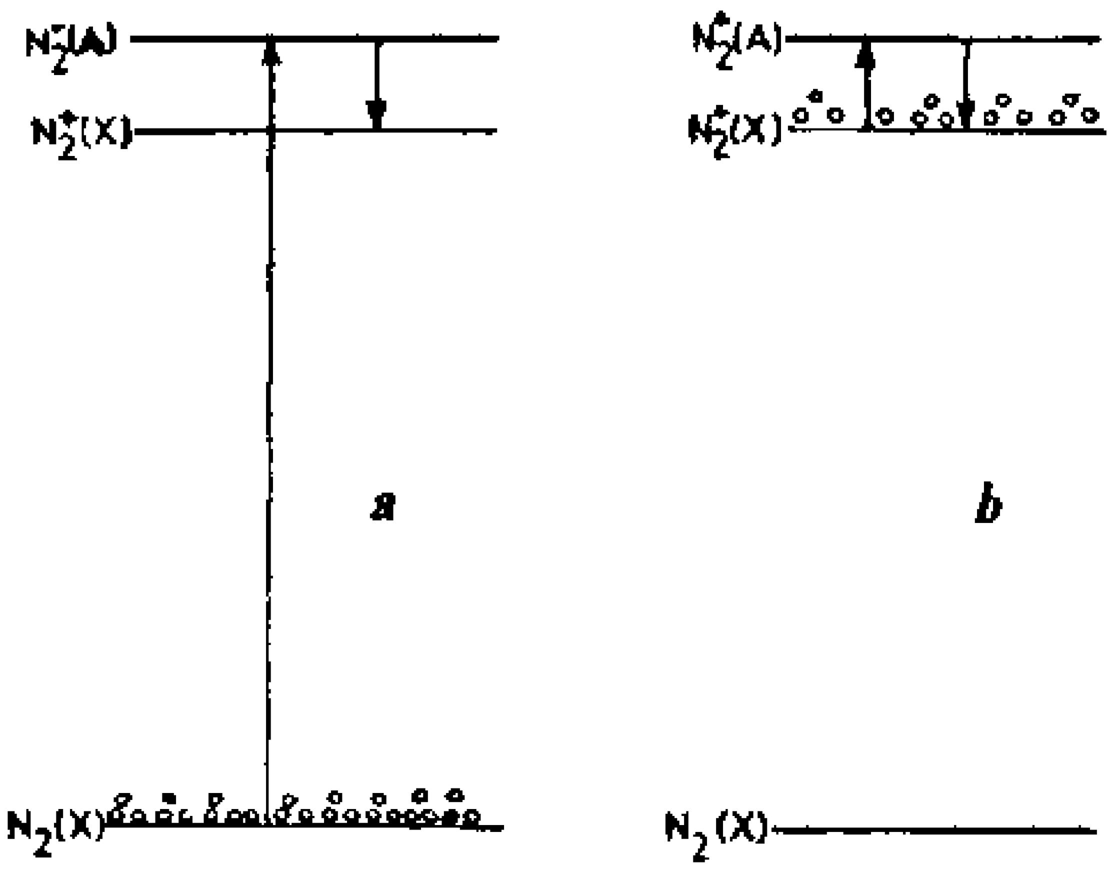

Figure 3. Twilight airglow emission from N_2^+ ions as proposed by (*a*) Saha and (*b*) Wulf and Deming.

Since the number of photons corresponding to wavelengths ($\lambda < 661$ Å emitted from the Sun at 6500 K is very small, to explain the observed intensity of twilight airglow N_2^+ emission, Saha proposed that the Sun would emit lines in the far-ultraviolet region a million times stronger than the background radiation. Actually, observations from rocket-borne spectrographs showed the presence of strong emission lines in the extreme-ultraviolet region of the solar spectrum.

Wulf and Deming[9] were of the opinion that in the upper atmosphere there are a sufficient number of N_2^+ ions in the lowest state. By absorbing sunlight, N_2^+ (X) ions are excited to N_2^+ (A) excited state, and subsequent transition to the lowest state of the ion gives rise to N_2^+ twilight airglow emission:

$$N_2^+(X) + h\nu \rightarrow N_2^+(A)$$
$$N_2^+(A) \rightarrow N_2^+(X) + h\nu.$$

Bates[10] critically examined the two processes and came to the conclusion that the process proposed by Wulf and Deming holds good as the lines emitted by the Sun in the far-ultraviolet region are not strong enough (a million times) as assumed by Saha.

The information obtained from rocket and satellite experiments in ultraviolet and X-ray solar radiation clearly indicate the importance of such studies for understanding upper-atmospheric phenomena. Saha had asserted the importance of observations from space for such studies many years ago.

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