were made using a water-cooled hollow cathode source, operated at about 1-mm pressure of argon. The resonance lines were investigated first with a thirty-foot grating in the second order, and with iron and krypton comparison spectra. Components *a* and *d* of the 4101A line were resolved by this instrument while components *b* and *c* were not. The 4511A line complex appeared as two components. A further check was made with the hollow cathode using a Fabry-Perot interferometer as before, with a 1.0-cm spacer.

The results of the wavelength determination from the atomic beam and hollow cathode sources, together with values taken from literature, are given in Table II. Center-of-gravity values for various combinations of components are also given in this table to facilitate comparison.

PHYSICAL REVIEW VOLUME 91, NUMBER 2 JULY 15, 1953

Intensity of Lyman-Alpha Line in the Solar Spectrum*

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(Received March 31, 1953)

The Lyman-alpha line appeared on a rocket spectrogram recently obtained by a group at the Physics Department of the University of Colorado. The grazing-incident spectrograph had been pointed directly at the sun during the 28-second exposure by a biaxial sun-follower in an Aerobee rocket. The average altitude during exposure was 81 km. Lyman-alpha was the only line observed in the far ultraviolet. It is about 5 angstroms broad and exhibits, for the altitude range of the rocket during the exposure, a narrow emission center with broad emission wings. The total intensity outside the earth's atmosphere is estimated to be 0.05 microwatt/cm². Instrumental scattering could have masked the light of any faint far-ultraviolet continuum which may have penetrated to the atmospheric levels reached by the rocket during the exposure.

INTRODUCTION

AFTER rockets were first sent above the ozone layer the extension of the solar spectrum well into the ultraviolet below 2900A was soon realized. On October 10, 1946 a Naval Research Laboratory group[1] succeeded in obtaining spectrograms reaching to about 2200A with a normal-incidence grating spectrograph employing two slits and utilizing lithium fluoride beads to focus the sun's light on the slits. Later, Hopfield and Clearman[2] analyzed photographs taken with similar grating spectrographs flown in rockets on April 1 and July 29, 1947. Slightly better dispersion and resolution were realized, but nothing essentially new was added to the knowledge of solar ultraviolet radiation. A sun "homing" device in connection with two partially diffusing mirrors was employed to illuminate the slits of the July instrument. Over the past few years spectrographs have been repeatedly flown, mostly under the supervision of R. Tousey of the Naval Research Laboratory. A few salient results of all these investigations are the discovery of the emission cores in the center of the two Mg II lines near 2800A, the identification of many new Fraunhofer lines and the measurement of the intensity of the solar continuum down to about 2000A. It had been expected that Lyman-alpha, the first line of the hydrogen Lyman series, might be detected photographically in the solar spectrum, but no evidence of the line was ever thus obtained. (Lyman-alpha is actually a doublet resulting from the $1s^2S-2p^2P^o$ transition in the hydrogen atom; the wavelengths are 1215.668A and 1215.674A.) Intensity losses suffered in reflecting the sun's light into the slit are great for wavelengths below 1500A, so that decreased spectrographic speeds resulting from this fact might account for the failure. In the meantime, other methods were tried for detecting light near and around the 1216A region. Tousey, Watanabe, and Purcell[3] flew a thermoluminescent phosphor, $CaSO_4$:Mn, in rockets to heights of between 82 and 127 km. Evidence for radiation lying between 1050 and 1250A was obtained. The intensity was estimated to be about 0.04 microwatt/cm².

Recently detection of solar radiation between 1180A and 1300A has been made with the aid of photon counters flown in rockets.[4] The radiation was not present below 74 km. Atmospheric absorption coefficients calculated from the data are consistent with the assumption that the radiation is from Lyman-alpha.

After the successful development of a biaxial sun-follower by the University of Colorado Physics Department electronics group, under contract with the Air Force, it was thought that Lyman-alpha may be photographed using a grazing-incidence-type, low dispersion, grating spectrograph. The speed of this instru-

* The research reported in this paper has been sponsored by the Geophysics Research Directorate of Air Force Cambridge Research Center, Air Research and Development Command.

[1] Baum, Johnson, Oberly, Rockwood, Strain, and Tousey, Phys. Rev. **70**, 781 (1946).

[2] J. J. Hopfield and H. E. Clearman, Phys. Rev. **73**, 877 (1948).

[3] Tousey, Watanabe, and Purcell, Phys. Rev. **83**, 792 (1951).

[4] Byram, Chubb, Friedman, and Lichtman, J. Opt. Soc. Am. **42**, 876 (1952).

TABLE I. Grating and optical constants for rocket spectrograph.

Grating constant	Radius	Angle of incidence	Resolution (theoretical)	Dispersion	Slit
6000 lines/cm	49.80 cm	85.0°	0.10A at 1216A 0.30A at 3000A	13A/mm at 1216A 19A/mm at 3000A	Width, 4 microns Length, 1 cm

ment at 1216A, because of the grazing-incidence feature and the fact that the slit could be illuminated directly by the sun, was much higher than that of other rocket instruments not possessing these features. The success of the Aerobee flight at Holloman Air Development Center, and the discovery of the Lyman-alpha line has recently been reported.[5]

THE SPECTROGRAPH

Pertinent constants of the instrument are listed in Table I. Eastman 103 uv-sensitized 16-mm film was used. The film was pulled into a light-tight steel cassette after exposure. The magnetically controlled shutter and the film-wind motor were activated by means of a cam-driven timer. The grating was ruled on soft glass coated with aluminum, blazed for the ultraviolet. Tests made previous to the flight in a vacuum chamber with 12-kv capillary discharge in air as source indicated that the spectrograph had good focus in the Lyman-alpha region, with a resolving power (limited by the 103 uv film) of about one-third that predicted by the standard formula. In the Lyman-alpha region about one-fourth of the light striking the slit reached the first-order spectrum.

THE SPECTROGRAM

A negative of the spectrogram taken by the University of Colorado Physics Department group[5] on December 12, 19:38 UT, 1952 is shown in Fig. 1. The densities have been altered in printing for the sake of clarity. The solar continuum from above 2000A through the visible to 5000A can be seen with its typical array of Fraunhofer lines. Beyond 5000A, where uv 103 film is no longer sensitive to the visible, the second order of the 2500A–3500A region may be seen. Lyman-alpha stands by itself above a dense background caused by instrumental scattering. A print of the Lyman-alpha line, magnified, appears in Fig. 2.

The exposure time was 28 seconds, and the average height of the rocket during exposure, 81 km. There

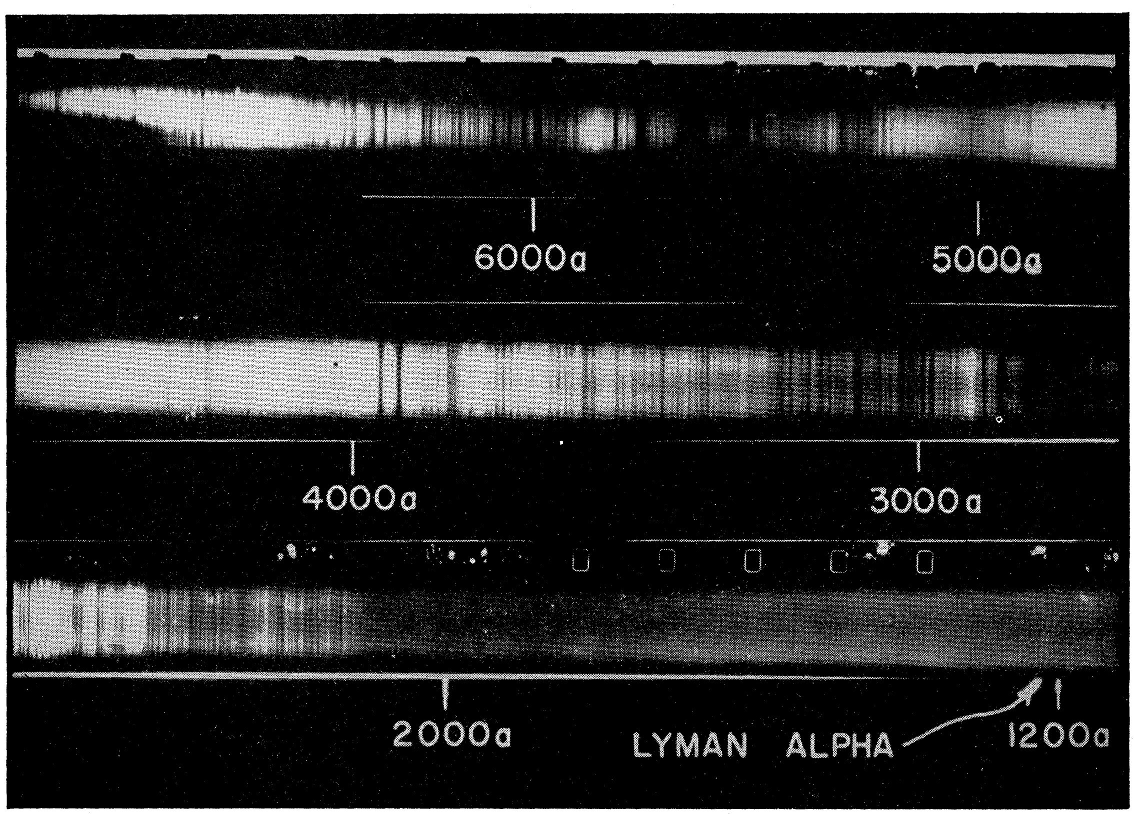

FIG. 1. A negative of the rocket spectrogram showing the Lyman-alpha line, and the solar continuum with Fraunhofer lines from about 2000A to 5000A. Beyond 5000A the second-order ultraviolet comes in because of decreased film sensitivity for the longer wavelengths.

[5] Pietenpol, Rense, Walz, Stacey, and Jackson, Phys. Rev. **90**, 156 (1953).

were no other emission lines in the far ultraviolet. Recourse had to be made to instrument constants in determining the wavelength of Lyman-alpha. These constants were established from a calibration spectrum. The wavelength was fixed at 1215.5A±1.0A. The solar continuum is obviously apparent to about 2100A, but careful inspection of the original film reveals the presence of Fraunhofer absorption lines to nearly 1800A. Microphotometric traces of this region, not yet analyzed, indicate that the continuum extends to perhaps 1700A. There is no evidence on the tracings of a continuum between 1700A and Lyman-alpha, or beyond.

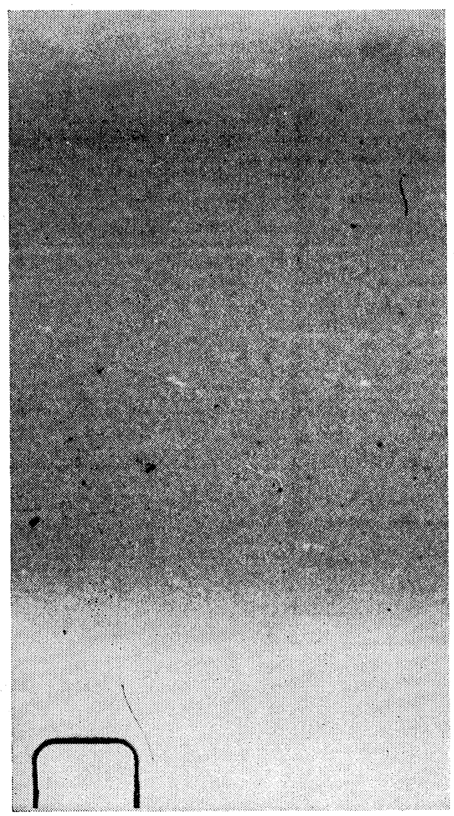

FIG. 2. A print of the Lyman-alpha line, greatly enlarged.

The intensity of general instrumental scattering, however, was very great so that any faint continuum that might be present at the altitude of the rocket would have escaped detection.

Each of the Mg II emission lines appeared split into two lines in the first order. The splitting may be due to an instrumental effect, induced by the conditions of the rocket flight. There was no doubling in the second-order Mg II lines but here the resolution was poorer and could have masked it. The doubling effect was not present in the capillary discharge spectra which were taken before the flight. The analysis of the ultraviolet continuum will be reported at another time.

INTENSITY OF LYMAN-ALPHA

Figure 3 is a plot for Lyman-alpha of intensity per angstrom against wavelength. It was assumed that the (uniform) background present on the spectrogram was entirely due to instrument scattering. This background was present in test spectrograms of sunlight taken on the ground previous to the flight. The shape of the curve was established by combining several microphotometric tracings taken across the line at various places along the spectral image of the line. The intensities were established in the following way: Relative intensities were obtained from standard H and D curves in this region. Rough measurements of the fraction of the light (in the 1216A region) striking the slit which was reflected into the first order spectrum at Lyman-alpha, and an assumed value[6] of the film's sensitivity in this region led to approximate values of absolute intensities at various parts of the line. Finally these intensities were corrected for atmospheric extinction[3] above 80 km. Variations in extinction with wavelength near 1216A were ignored for this calculation.

The maximum width of the line is about five angstroms. Some of the broadening undoubtedly is instrumental. However, measurements of the width of lines in the air spectrum (near 1216A) taken with a capillary discharge tube before the flight indicated that even those lines broadened by Stark effect were no more than one angstrom in maximum width.

It is clear from the above that not too much weight can be given to the aspect of the curve in Fig. 3 and to the values of the intensities given there. Nevertheless it is interesting to note that the integrated intensity of the line is 0.05 microwatt/cm^2 (outside the earth's atmosphere), a value very much in accordance with data previously mentioned.[3] The two wings of the line may be manifestations of the same phenomena that give rise to the splitting of the Balmer-alpha emission line when flare conditions prevail on the sun's surface.

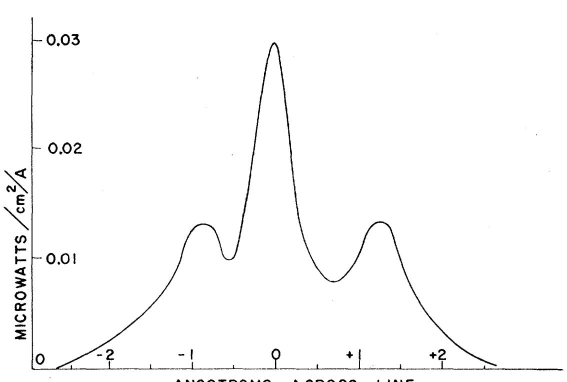

FIG. 3. A curve showing variation of intensity with wavelength across the Lyman-alpha line. A narrow emission center and two unsymmetrical emission wings are characteristic features. Integrated intensity is 0.05 microwatt/cm^2.

[6] Submitted by R. Tousey.

In the latter case it has frequently been proposed that the source of the radiation is in the lower layers in the sun's atmosphere, and that the cooler gases above absorb the center portion. In the case of Lyman-alpha the wing portion may be due to an effect such as this, while the center portion may be attributed in part to emission from clouds of excited hydrogen gases at higher levels. Another explanation takes into account the fact that extinction of Lyman-alpha by the earth's atmosphere increases rapidly[7] on both the short and long wavelength sides of 1216A. Therefore, the 5A width stated here is a minimum. The dips may represent absorption in a continuum which extends on both sides of the center of the line.

The outer portions of the Lyman-alpha radiation would be absorbed at different heights and, should the intensity of the radiation at the extremities of the line vary appreciably with solar activity, one might then expect changes in the ionosphere at corresponding heights.

Solar activity on December 12, 1952, the day of the flight, was above average.[8] A very active center in the western hemisphere of the sun was probably responsible for the aurora display December 12 and the magnetic storm December 13. Two small flares occurred shortly after the flight—one a so-called dark flare.

CRPL records of ionosphere behavior reveal that important disturbances were present on December 12 and 13, 1952. Around noon on the former day absorption and blanketing (presumably in the *D* layer) prevented observations of *E* layer reflections. Ionospheric disturbances on December 13, especially a sporadic *E* increase, point to corpuscular effects in the earth's atmosphere. These conditions would be typical if a solar flare of appreciable intensity had occurred on December 12.

The spectrogram indicates that much of the 1216A radiation reached levels around 81 km and lower. Since the average virtual height of the *E* layer for December 12 in the White Sands region is 100 km, it appears that much of the Lyman-alpha line radiation penetrated and was absorbed in the *D* layer. Moreover, in view of the above mentioned solar and ionospheric observations, Lyman-alpha intensity was probably above average. Although no flare was in progress at the time of the flight, flare conditions prevailed—a situation known to frequently result in increased Balmer-alpha emission. The noon-day disturbance in the *D* layer noted above might therefore be attributed to the presence of enhanced Lyman-alpha radiation from the active regions of the sun.

It does not seem unlikely that other members of the Lyman series, the Lyman continuum, and perhaps helium emission lines, if present in the solar spectrum, may be photographed with instruments similar to the one used in this flight. Further rocket flights utilizing the biaxial sun-follower and grazing-incidence spectrographs are planned.

Dr. W. B. Pietenpol, Head of the Department of Physics of the University of Colorado, was the able supervisor of both the sun-follower and Lyman-alpha research programs. Much credit is due Dr. Marcus O'Day, Dr. Howard Edwards, and Dr. H. A. Miley, of the Air Force Cambridge Research Center for their farsightedness in sponsoring the ultraviolet program. Mr. D. S. Stacey and Professor F. C. Walz and their electronics laboratory group helped assure the success of the program by their assiduous work in developing the sun-follower. Mr. J. M. Jackson, research physicist, contributed greatly to the solving of the many difficulties encountered in all aspects of the development research. Much appreciation is expressed to the personnel of the Upper Air Laboratory of the University of Colorado for their contributions in the design, shop and optical work, and in particular to Mrs. Barbara Todd, Mr. W. E. Behring, and Mr. J. P. Curtis for skillful help with the optical adjustments and the photometry. The writer is greatly indebted to Dr. K. Watanabe, Dr. Y. Tanaka, and other members of the Geophysics Research Directorate, Air Force Cambridge Research Center, for their critical review of the instrument design and their encouraging suggestions. A very fruitful discussion of the spectrogram with Dr. R. Tousey and Mr. F. S. Johnson of the Naval Research Laboratory is acknowledged with pleasure. The writer is very grateful to Dr. W. O. Roberts of the High Altitude Observatory for comments and information concerning solar activity and ionospheric conditions on the day of the rocket flight.

[7] K. Watanabe (private communication).
[8] Dorothy E. Trotter and W. O. Roberts (private communications).

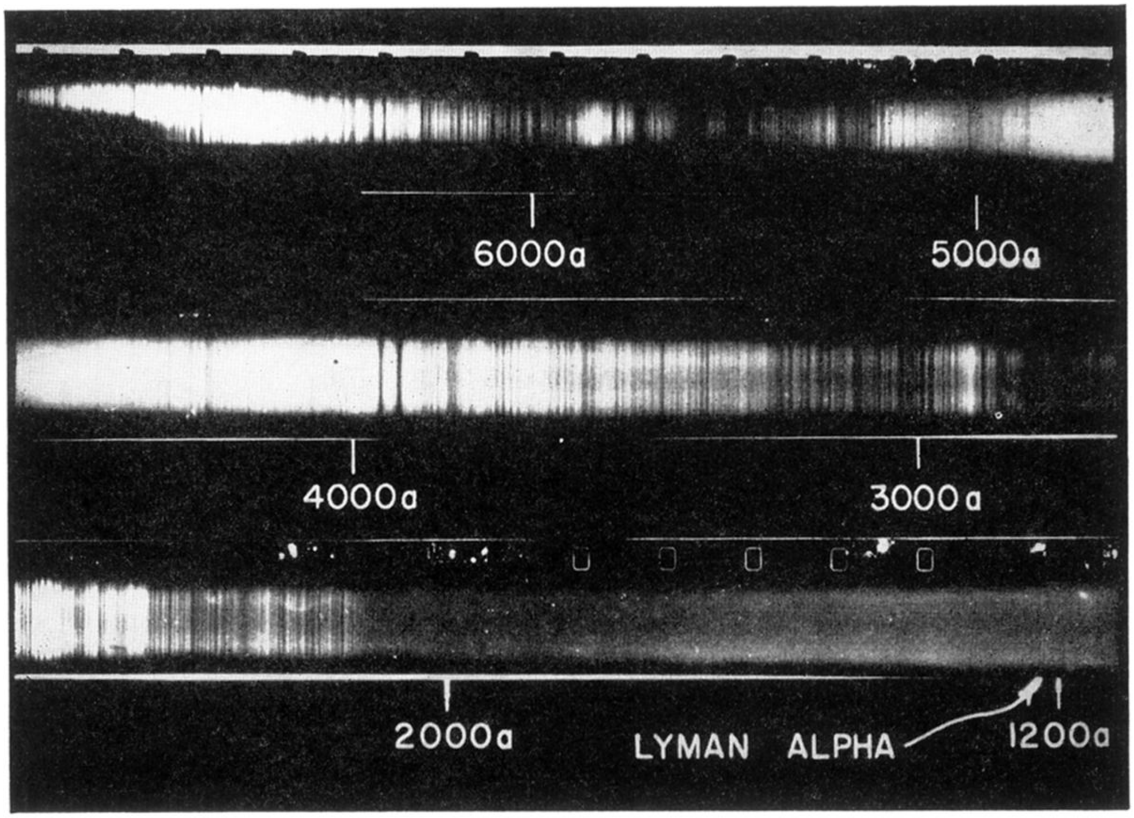

FIG. 1. A negative of the rocket spectrogram showing the Lyman-alpha line, and the solar continuum with Fraunhofer lines from about 2000A to 5000A. Beyond 5000A the second-order ultraviolet comes in because of decreased film sensitivity for the longer wavelengths.

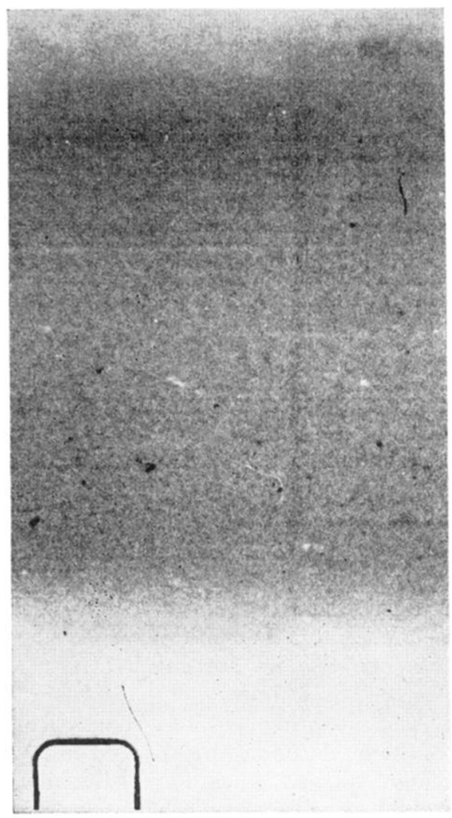

FIG. 2. A print of the Lyman-alpha line, greatly enlarged.