

Mariner 9 Ultraviolet Spectrometer Experiment: Mars Airglow Spectroscopy and Variations in Lyman Alpha

C. A. BARTH, A. I. STEWART, AND C. W. HORD

*Department of Astro-Geophysics and Laboratory for Atmospheric and Space Physics,
University of Colorado, Boulder, Colorado 80302*

AND

A. L. LANE

Jet Propulsion Laboratory, Pasadena, California 91103

Received June 9, 1972

Mariner 9 ultraviolet spectrometer observations show the Mars airglow consists principally of emissions that arise from the interaction of solar ultraviolet radiation with carbon dioxide, the principal constituent of the Mars atmosphere. Two minor constituents, atomic hydrogen and atomic oxygen, also produce airglow emissions. The airglow measurements show that ionized carbon dioxide is only a minor constituent of the ionosphere. Using the airglow measurements of atomic oxygen, it is possible to infer that the major ion is ionized molecular oxygen. The escape rate of atomic hydrogen measured by Mariner 9 is approximately the same as that measured two years earlier by Mariner 6 and 7. If the current escape rate has been operating for 4.5 billion years and if water vapor is the ultimate source, an amount of oxygen has been generated that is far in excess of that observed at present. Mariner 9 observations of Mars Lyman alpha emission over a period of 120 days show variations of 20%.

INTRODUCTION

In July and August of 1969, the first ultraviolet spectra of the airglow of Mars were obtained with the ultraviolet spectrometers on board Mariner 6 and 7. Because of the high information content in these spectroscopic observations, it has been possible not only to identify the atoms and molecules that are the principal contributors to the Mars airglow, but to determine the excitation mechanisms as well. From the airglow data, it has been possible to construct model atmospheres showing the distribution of both the neutral and ionized constituents of the Mars upper atmosphere.

Starting on 14 November 1971, the Mariner 9 ultraviolet spectrometer measured the upper atmosphere airglow of Mars over a time period of 120 days. The large number of Mariner 9 observations has produced not only spectroscopic data of

greater precision, but, in addition, measurements of variations that occur in the Mars airglow over an extended time period. Some of the results of these observations will be reported here. As part of the symposium proceedings, there are additional reports on the Mariner 9 ultraviolet spectrometer on the following subjects: structure of the Mars upper atmosphere and its variations (Stewart *et al.*, 1972), determination of the topography of Mars from the ultraviolet photometry of the lower atmosphere and surface (Hord *et al.*, 1972), and the occurrence of ozone in the polar regions on Mars (Lane *et al.*, 1972). In this report, the airglow spectrum of Mars will be described using the high-quality Mariner 9 data. Models for the Mars neutral and ionized atmosphere will be presented using results that were first recognized from the Mariner 6 and 7 ultraviolet observations. Finally, Mariner

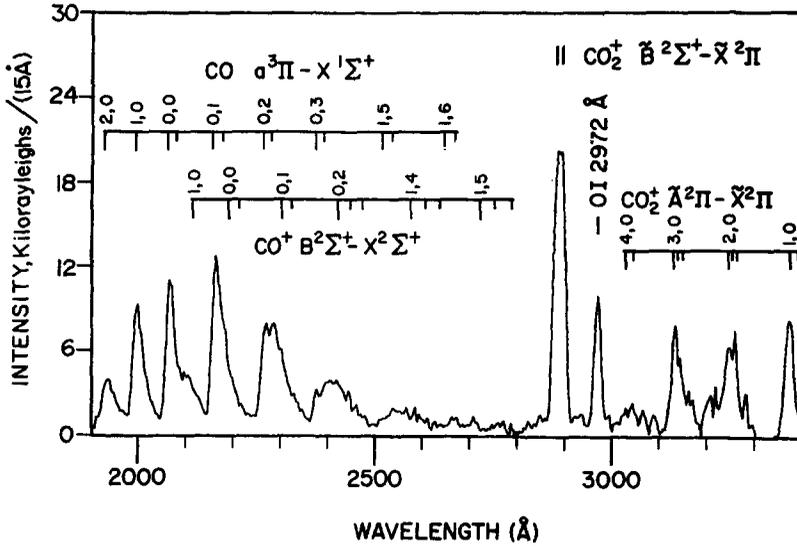


FIG. 1. Mars airglow spectrum 1900–3400 Å. This spectrum is the result of averaging 120 individual limb observations with 15-Å resolution.

9 observations of the atomic hydrogen Lyman alpha intensity and its variations are compared with an indicator of solar activity.

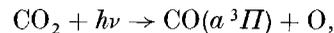
MARS AIRGLOW 1900–3400 Å

In Fig. 1, the spectrum of the Mars airglow in the 1900–3400-Å wavelength region is displayed. This spectrum was produced by averaging 120 individual spectral observations obtained by the Mariner 9 ultraviolet spectrometer on several different orbits while tangentially viewing the sunlit atmosphere of Mars in the altitude range 100–150 km. Pertinent instrument characteristics are: the entire spectral range between 1100 and 3500 Å is scanned every three seconds at a spectral resolution of 15 Å and the data are recorded simultaneously on two photomultiplier tubes with different photocathodes. The spectra used in Fig. 1 were recorded by the photomultiplier tube with a cesium telluride photocathode and the spectra used to produce Fig. 2 were measured by the tube with a cesium iodide photocathode.

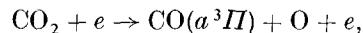
What is remarkable about the Mars airglow spectrum in Fig. 1 is that all of the emissions originate from the direct or

indirect action of solar ultraviolet radiation on carbon dioxide, CO_2 . This is the airglow spectrum of an essentially pure carbon dioxide atmosphere. The most intense ultraviolet emission, the $\text{CO } a^3\Pi - X^1\Sigma^+$ Cameron bands in the 1900–2700-Å range in Fig. 1, are produced by three processes which dissociate carbon dioxide:

photodissociative excitation



electron-impact dissociative excitation



and dissociative recombination



(McConnell and McElroy, 1970; Barth *et al.*, 1971; Stewart, 1972; Stewart *et al.*, 1972). In all three cases, the first step in the excitation process is the absorption of a solar ultraviolet photon by carbon dioxide. Therefore, in the altitude region that is optically thin to ultraviolet radiation, the intensity of this emission is proportional to the density of carbon dioxide. When, as in the case of Mariner ultraviolet observations, the airglow intensity is measured as a function of altitude,

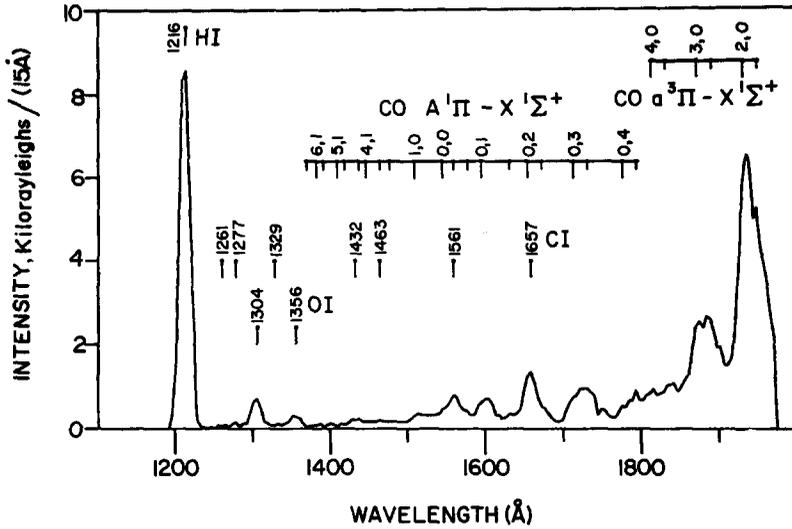


Fig. 2. Mars airglow spectrum 1100–1900 Å. This spectrum also is the result of averaging 120 individual limb observations with 15-Å resolution.

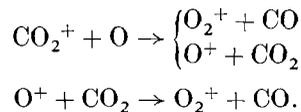
it becomes possible to determine the temperature of the upper atmosphere since

$$T = \frac{mg}{k} \frac{(z_2 - z_1)}{(\ln n_1 - \ln n_2)},$$

where m is molecular weight, g gravitational acceleration, k the Boltzmann constant, and n_1 the density at altitude z_1 . When such an analysis was performed on the Mariner 6 and 7 data, the temperature at the top of the Mars thermosphere was determined to be 350 K (Stewart, 1972). A similar analysis on the Mariner 9 ultraviolet data has shown that the comparable temperature is 325 K (Stewart *et al.*, 1972).

In the Mariner 9 airglow spectrum in Fig. 1, the two CO_2^+ band systems, $\tilde{A}^2\Pi - \tilde{X}^2\Pi$ and $\tilde{B}^2\Sigma - \tilde{X}^2\Pi$, between 2800 and 3400 Å are predominantly excited in the photoionization of carbon dioxide. Before the Mariner 6 and 7 ultraviolet observations, the major ion in the Mars ionosphere was assumed to be ionized carbon dioxide, CO_2^+ . Theoretical calculations based on such an assumption predicted that fluorescent scattering by CO_2^+ would be the principal source of the $A-X$ band system (Dalgarno *et al.*, 1970). A detailed spectroscopic analysis of the Mariner airglow spectrum revealed that not only did the

predicted intensities for the two band systems not agree with the data, but that the vibrational intensity distribution of the $A-X$ system was more appropriate to excitation by photoionization of carbon dioxide (Barth *et al.*, 1971). This result is verified in the Mariner 9 data as is revealed by a comparison of the relative intensities of the (2,0) and (3,0) bands, in Fig. 1 of this paper, with the same bands in Fig. 4 of Barth *et al.* (1971). It is now possible to infer theoretically that the major ion in the Mars ionosphere is ionized molecular oxygen, O_2^+ , as a result of a laboratory experiment performed in response to the new information present in the Mariner 6 and 7 ultraviolet data (Fehsenfeld *et al.*, 1970). Carbon dioxide ions are converted into molecular oxygen ions by reacting with the small amount of atomic oxygen that is present in the Mars atmosphere (Stewart, 1972):



MARS AIRGLOW 1100–1900 Å

In Fig. 2, the Mars airglow spectrum in the 1100–1900-Å region is displayed.

This spectrum was produced by averaging 120 individual spectral scans obtained simultaneously with the longer-wavelength spectra used in preparing Fig. 1. The carbon monoxide Cameron bands which are prominent in Fig. 1 appear in this spectrum longward of 1800 Å. Most of the other emissions that appear in this figure are also the result of dissociation processes involving carbon dioxide; namely, the CO $A^1\Pi-X^1\Sigma^+$ fourth positive bands, several atomic carbon lines, and the atomic oxygen 1356-Å line. However, there are two emissions that are produced by two minor constituents of the Mars upper atmosphere, the atomic hydrogen 1216-Å line and the atomic oxygen 1304-Å line. Both of these emissions are believed to be produced by resonance scattering of solar radiation by hydrogen and oxygen atoms in the Mars atmosphere. A measure of the intensity of these airglow lines is a measure of the density of these atoms. Using the oscillator strengths of the resonance transitions of the two atoms and the measured solar ultraviolet lines (Bruner and Rense, 1969; Barth, 1969), the amount of atomic hydrogen at 135 km may be calculated to be one part per million (Anderson and Hord, 1971), and the amount of atomic oxygen at the same altitude, 1% (Strickland *et al.*, 1972). Even though these are minor constituents, they have important roles both as indicators and participants in the photochemistry of Mars.

The Mariner 9 observations show that the atomic hydrogen Lyman alpha airglow decreases only slightly with increasing altitude over the range 100–800 km (see Fig. 4 of Barth *et al.*, 1972). This large apparent scale height results from the slowly changing density of this light atom with altitude and its moderate optical thickness. Such a calculation on the Mariner 6 and 7 data revealed the density at 200 km to be 3×10^4 atoms cm^{-3} and the exospheric temperature 350 K (Anderson and Hord, 1971). This same figure shows the intensity of 1304-Å atomic oxygen emission to be nearly constant for altitudes between 100 and 200 km and then to decrease with increasing altitude. This behavior is indicative of the

large optical depth of the Mars atmosphere to 1304-Å radiation. A radiative transfer calculation is required to determine the amount of atomic oxygen in the Mars atmosphere such as the treatment used with the Mariner 6 and 7 data (Strickland *et al.*, 1972).

MODEL ATMOSPHERE AND IONOSPHERE

A model atmosphere has been constructed based essentially on the Mariner ultraviolet spectrometer experiment results, the Mariner radio occultation experiment results, and some results of high-resolution spectroscopy from ground-based telescopes. In Fig. 3, the temperature profile is adapted from Stewart's (1972) heat balance calculations based on Mariner 6 and 7 measurements of the ultraviolet airglow. The density distribution of carbon dioxide is derived from this temperature profile and by setting the column density of CO₂ at 135 km equal to the amount necessary to produce the maximum rate of photoionization at the altitude where the radio occultation experiment measured the maximum electron density (Fjeldbo *et al.*, 1970; Barth *et al.*, 1971; Stewart, 1972). The implicit assumption of an essentially pure CO₂ atmosphere is based on the Mariner ultraviolet spectroscopy results. In this model, the amount of atomic oxygen is set at 1% at 135 km based on the radiative transfer calculations of Strickland *et al.* (1972). Diffusive separation is assumed to begin at 100 km and while this assumption is completely arbitrary, the conclusions based on the ionospheric calculations would not be changed unless the turbopause were higher by two or more scale heights. The amount of carbon monoxide, CO, and molecular oxygen, O₂, in the model is based on the results of ground-based observations, less than 0.1% for CO (Kaplan *et al.*, 1969) and slightly more than 0.1% for O₂ (Barker, 1972; Traub and Carleton, 1972). The amounts of carbon monoxide in the model at 150 and 170 km fall within the limits set by Thomas (1971) from an analysis of the Mariner 6 and 7 ultraviolet airglow

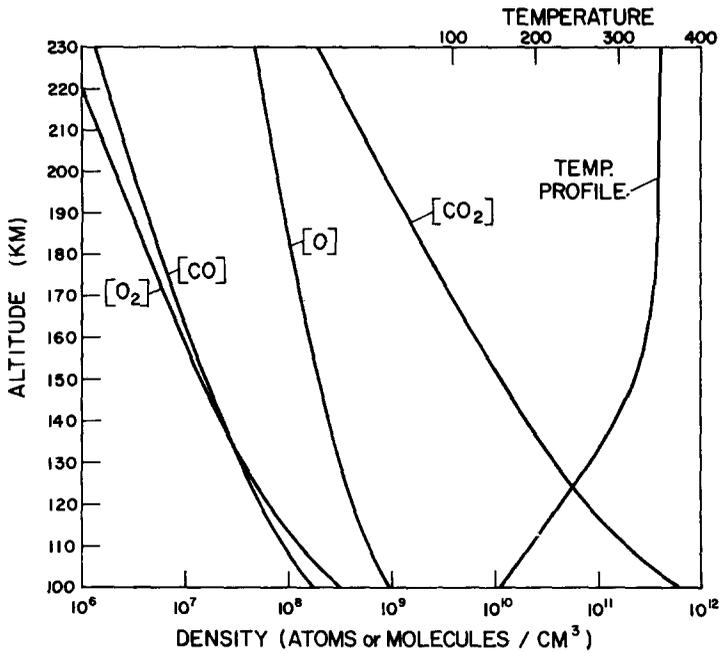


FIG. 3. Mars model atmosphere. This model atmosphere is based on Mariner 6 and 7 ultraviolet spectrometer and radio occultation results as well as ground-based telescope observations.

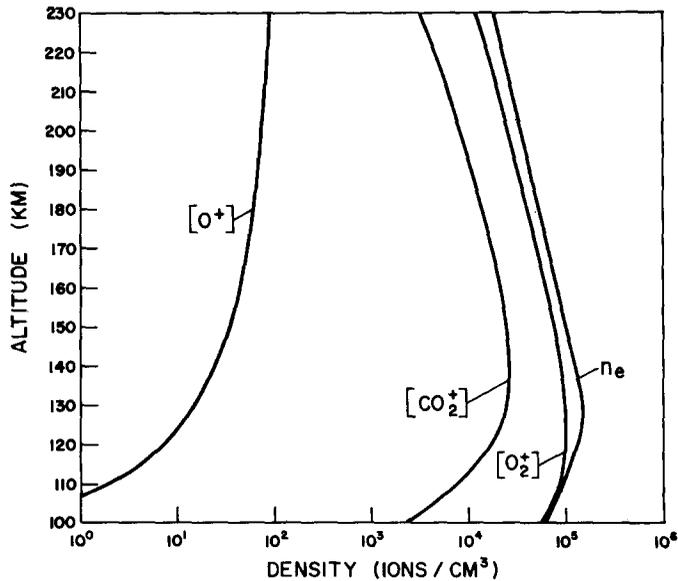


FIG. 4. Mars model ionosphere. This model ionosphere is calculated from the model atmosphere using Mariner 6 and 7 radio occultation results and laboratory measurements of ion chemistry.

spectrum. An important characteristic of this model atmosphere is that CO_2 is the major constituent throughout the altitude region where collisions and chemical reactions take place. The base of the exosphere, the region where collisions essentially do not occur, is at 230 km.

Using the neutral atom and molecule distribution in Fig. 3, the altitude distribution of ions in the Mars ionosphere was calculated using ion-molecule and ion-atom reactions. The most important reaction that determines the ion composition is the reaction between atomic oxygen and ionized carbon dioxide, measured in the laboratory by Fehsenfeld *et al.* (1970). The electron density used in the calculations was that measured by the Mariner 6 and 7 radio occultation experiment (Fjeldbo *et al.*, 1970). The results of these calculations, shown in Fig. 4, indicate that over the entire altitude range of this model ionosphere O_2^+ is the major ion. For the particular atomic oxygen concentration of 1%, the ratio of O_2^+ to CO_2^+ is approximately 3 to 1. For other concentrations of atomic oxygen, the ion composition would be different, with the ratio of O_2^+ to CO_2^+ approximately proportional to the concentration of atomic oxygen.

ESCAPE OF ATOMIC HYDROGEN

With the temperature and density of hydrogen atoms at the base of the exosphere determined from the Mariner ultraviolet observations, it is possible to calculate the rate of evaporative escape from the top of the Mars atmosphere. A form of the Jean's escape equation is

$$F = n \frac{\bar{v}}{4} \left(\frac{E_G}{E_K} + 1 \right) \exp \left(- \frac{E_G}{E_K} \right),$$

where F is the flux of escaping atoms, n is the density at the critical level (230 km on Mars), \bar{v} is the average thermal velocity of the atoms at that level, E_G is the gravitational energy which equals 0.123 eV for a hydrogen atom on Mars, and $E_K = kT$ is proportional to the kinetic energy of the atoms. Using the temperature and hydrogen atom density of 350 K and 3×10^4 atoms cm^{-3} that was measured in 1969, the

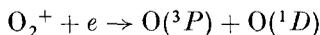
escape flux is calculated to be 2×10^8 atoms $\text{cm}^{-2} \text{sec}^{-1}$. In 1971 the Mariner 9 observations show a lower average temperature, 325 K, but the intensity of Lyman alpha emission, although variable, appears larger than in 1969. The result is that the escape flux calculated for the physical conditions in 1971 is approximately the same as it was in 1969; namely, 2×10^8 atoms $\text{cm}^{-2} \text{sec}^{-1}$. Since the time constant associated with emptying the Mars exosphere of hydrogen atoms is 4 hr and Mariner spacecraft have observed hydrogen in the Mars exosphere on two occasions in 1969 five days apart and then daily for a period of 120 days in 1971-72, there must be a source of atomic hydrogen that is currently supplying atomic hydrogen to the exosphere.

PHOTODISSOCIATION OF WATER VAPOR

An attractive source to supply the hydrogen atoms that are escaping is the same source that is believed to produce the hydrogen atoms that escape from the top of the earth's atmosphere; namely, the dissociation of water vapor. Water vapor has been observed and measured in the lower atmosphere of Mars by the Mariner 9 infrared interferometer spectrometer (Hanel *et al.*, 1972), during the same time period of the ultraviolet observations. The amount detected is more than ample to supply the atomic hydrogen observed escaping from the exosphere if the water vapor were exposed to unattenuated solar ultraviolet radiation. However, the photodissociation of water vapor in the lower atmosphere is slow because of attenuation and the amount in the higher atmosphere is severely limited by the cold trap at the top of the Mars troposphere (Hanel *et al.*, 1972; Kliore *et al.*, 1972). Because of this, Hunten and McElroy (1970) have suggested a mechanism where molecular hydrogen is formed in the lower atmosphere from the photodissociation of water vapor and transported into the upper atmosphere where it is dissociated by chemical reactions or solar radiations. In this model, a reservoir of molecular hydrogen is the current source of atomic hydrogen for

exospheric escape, but the ultimate source is still the dissociation of water vapor.

If atomic hydrogen has been escaping from Mars at the current rate for 4.5 billion years and if water vapor has been the source of atomic hydrogen over that time period, the amount of liquid water that would be required to supply the hydrogen would be the equivalent of 4ms evenly distributed over the surface of Mars. In the process of photodissociation, oxygen atoms would be produced that, because of their greater mass, would have a negligible opportunity to escape by atmospheric evaporation. If these atoms were combined to form oxygen molecules and remained in the atmosphere, an amount equivalent to 2.5km-atom would have accumulated. The amount of molecular oxygen that is presently observed in the Mars atmosphere is 10cm-atom (Barker, 1972; Traub and Carleton, 1972) or 4×10^{-5} times less. The oxygen may have reacted with the surface material in which case approximately 10^{25} atoms cm^{-2} would need to be chemically combined with the surface material. The idea that there may be nonthermal methods by which atoms can escape from the Mars atmosphere has been examined by McElroy (1972) and indeed he has suggested that there are processes that can lead to the escape of atomic oxygen. The gravitational energy that an oxygen atom needs to have in order to escape from the Mars exosphere is 1.97eV. McElroy has suggested that oxygen atoms produced in the Mars ionosphere may receive this energy through dissociative recombination. Recombination of the major ion, O_2^+ , leads to two oxygen atoms with excess energy of 2.5eV



and recombination of the next most abundant molecular ion, CO_2^+ , leads to a single oxygen atom with excess energy of 4.0eV



ACCRETION FROM THE SOLAR WIND

At the orbit of Mars, the flux of solar wind protons is on the average $1-2 \times 10^8$

protons $\text{cm}^{-2}\text{sec}^{-1}$. Since the magnitude of this flux of atomic hydrogen ions is strikingly similar to the escape flux of hydrogen atoms from Mars, it is appropriate to consider whether or not there is any connection between the two. Since Mars has essentially no permanent magnetic field, there is no magnetosphere to divert the solar wind from impinging on the Mars atmosphere; the Earth's magnetosphere causes the solar wind to flow around the Earth. If the solar wind protons did impinge on the Mars atmosphere, they would undergo charge transfer by the time they penetrated to the 150-km level. After thermalizing, these newly accreted hydrogen atoms could become part of the supply of hydrogen atoms to the exosphere. However, according to current theoretical ideas about the interaction of the solar wind with Mars, the solar wind protons do not impinge on the atmosphere (Dessler, 1968). Since the upper atmosphere of Mars contains a highly conducting ionosphere and the solar wind carries with it a magnetic field, the relative motion of the two causes a current to flow in the ionosphere producing a magnetic field in such a direction so as to impede the flow of the solar wind. Thus, Mars has an induced magnetosphere that causes the solar wind protons to flow around the planet and not be accreted by its atmosphere.

VARIATIONS IN LYMAN ALPHA INTENSITY

The Mariner 9 ultraviolet spectrometer is able to measure the 1216-Å Lyman alpha emission line both when viewing the planetary limb and when looking directly down at the disk of Mars. This emission line is essentially uncontaminated by background radiation from the lower atmosphere since carbon dioxide absorbs the incoming solar radiation high in the atmosphere. During the Mariner 9 operations, measurements of the disk were made on every orbital revolution, while limb observations were made on only selected orbital passes. Most of the limb observations were conducted approximately 15 minutes before periapsis, after the instru-

ments had completed a set of disk observations and prior to additional measurements of the planetary surface. The limb observations were accomplished by aiming the field of view of the spectrometer at a point approximately 1000 km above the surface and allowing the spacecraft motion to carry the field of view downward through the atmosphere. Figure 5 shows the Lyman alpha emission rate as a function of altitude for a typical limb observation; this particular one was conducted on 28 November 1971. Each individual data point is produced by fitting a triangular slit function to individual spectra using a least squares fit technique. In Fig. 5, a least-squares fit has been made to some ninety individual

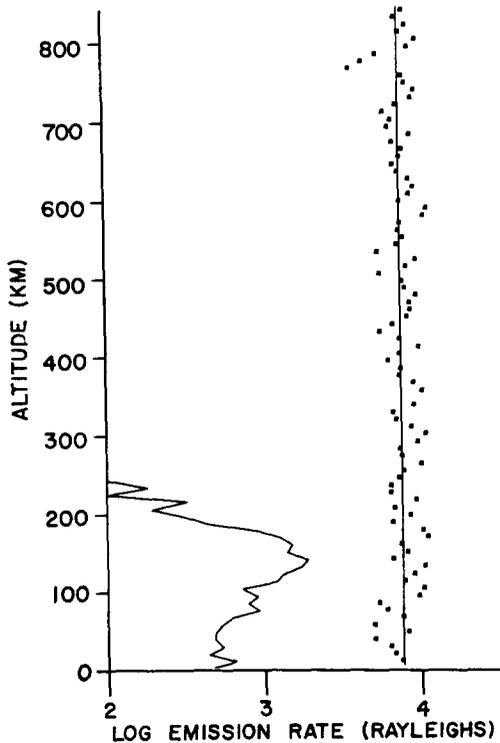


FIG. 5. Limb measurement of Lyman alpha airglow. Emission rates of individual Lyman alpha measurements are plotted as small squares. The nearly vertical line is a least-squares fit to these points. In the lower left-hand portion of the graph, the CO ($A-X$) + CI airglow originating from carbon dioxide is plotted to show the altitude where the airglow emission is a maximum.

measurements to produce the nearly vertical straight line. The altitude where the maximum intensity occurs in the carbon dioxide airglow, slightly below 150 km, may be seen from the altitude profile also shown in the figure.

Lyman alpha measurements which were made across the disk of Mars for the same orbit on 28 November 1972 are shown in Fig. 6 with the emission rate plotted as a function of time of observation. The location of the limb measurements (on the left of the figure) is facilitated by the use of the carbon dioxide airglow data which also appear in the figure. In this particular orbital pass, the intensity of the Lyman alpha emission is 7.2 kilorayleighs at the altitude where the carbon dioxide airglow reaches its maximum. At the location where the field of view crosses onto the illuminated disk, the solar zenith angle is 32° and the Lyman alpha intensity 7.0 kilorayleighs. The Lyman alpha emission rate decreased as the observation proceeded across the planet, reaching 2.7 kilorayleighs at the terminator.

Since the Mariner 9 Lyman alpha observations were made under a variety of observing geometries, it is necessary to compare measurements made under similar conditions at different times to determine if temporal variations occur. Such a comparison has been made both for limb measurements and for measurements made while viewing the planetary disk. Variations in the Lyman alpha intensity measured at the limb are shown in Fig. 7. The Lyman alpha intensity was measured at the altitude where the carbon dioxide airglow was a maximum, approximately 150 km, for 12 orbital passes in November and December 1971. The solar zenith angle was 32° at every limb crossing. Variations in intensity of 20% do occur. For comparison, an indicator of solar activity, the 10.7-cm radio flux, has been plotted for the same time period. A particular difficulty in comparing Mars observations with solar activity indicators is that the portion of the solar disk illuminating the Mars atmosphere is not accessible for observation from the Earth at the same time. For measurements

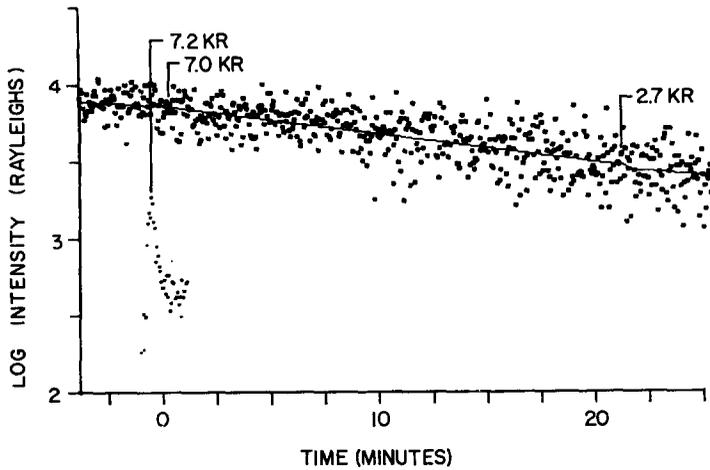


FIG. 6. Measurement of Lyman alpha airglow across Mars' disk. Lyman alpha intensity (emission rate) measurements are plotted as small squares as a function of time of observation. The time the field of view passes onto the planetary disk is indicated as zero; to the left of zero are measurements of the limb. The CO (A-X) + CI airglow is plotted in the lower left-hand portion to indicate the location of the maximum airglow emission. The terminator crossing occurred at 22 min. At the following locations, Lyman alpha intensities are: at the airglow maximum, 7.2kR; on the disk near the limb, 7.0kR; and at the terminator, 2.7kR.

made at the end of November 1971, there was a three-day lag between the times when a particular location on the Sun

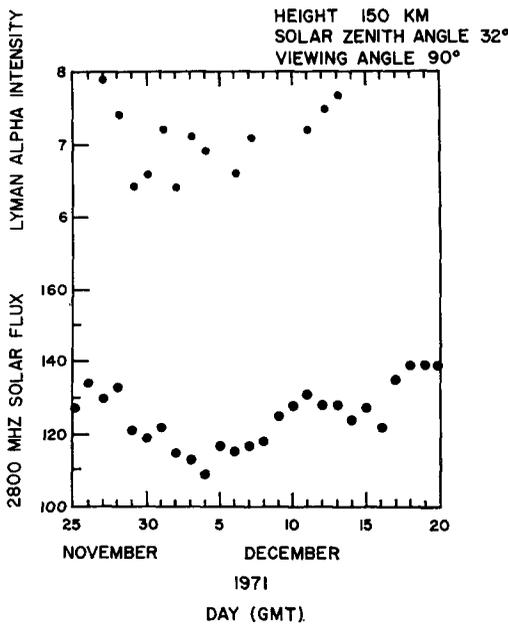


FIG. 7. Comparison of limb Lyman alpha intensity with 10.7-cm solar radioflux (2800MHz solar flux).

faced Mars and when it faced the Earth (Barth *et al.*, 1972). There is the suggestion in the figure that the variation in the Mars Lyman alpha intensity does anticipate the variation in the solar flux indicator by several days.

Observations of the Lyman alpha intensity from the disk of the planet, made during a 39-day period in January and February 1972, are shown in Fig. 8. The Lyman alpha measurements used were obtained under similar viewing conditions, where the solar zenith angle was 45° and the instrument viewing direction was vertical. The disk emission rates are smaller than those from the limb and also vary in intensity with a range of 20% or more. The 10.7-cm radio flux, also plotted in the figure, shows a variation that is the same in phase but different in magnitude than the Lyman alpha intensity, when allowance is made for the seven-day delay appropriate to these observations.

SOURCE OF LYMAN ALPHA VARIATION

With the excitation mechanism of the Mars Lyman alpha airglow identified as

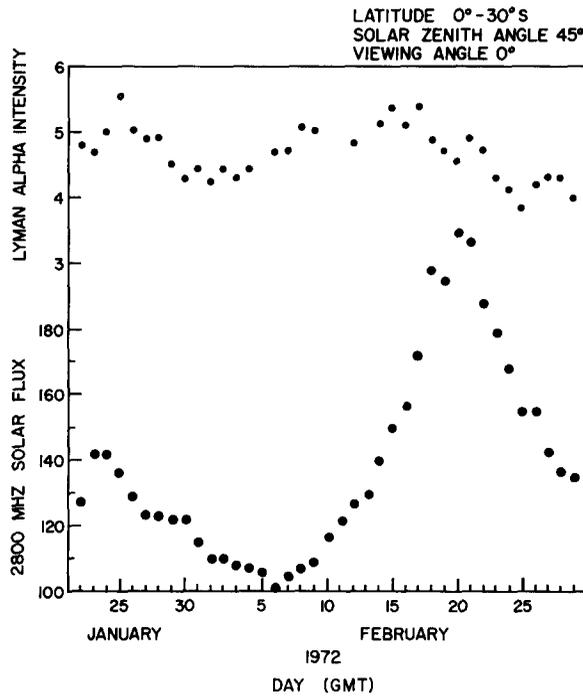


FIG. 8. Comparison of disk Lyman alpha intensity with 10.7-cm solar radioflux (2800MHz solar flux).

resonance scattering of solar Lyman alpha photons by atomic hydrogen in the Mars atmosphere, the most plausible explanation of the variation in the Mars Lyman alpha airglow is that either the number of hydrogen atoms in the Mars atmosphere is changing or that the flux of the solar Lyman alpha radiation is changing, or that both mechanisms are operating. In the case of the Earth's Lyman alpha airglow, there is evidence that both types of changes occur. In the Earth's exosphere, the number of hydrogen atoms changes throughout the 11-year solar cycle in response to a changing escape flux brought about by changes in the thermospheric temperature (Kockarts and Nicolet, 1962). Shorter term variations in satellite measurements of the Earth's Lyman alpha radiation have been attributed to the variability of the Lyman alpha flux at the center of the solar emission line (Meier, 1969). Measurements of the solar emission line show that the flux in the center of the line does vary and

that this variation may be correlated with the Zurich sunspot number (Blamont and Vidal-Madjar, 1971; see also Thomas and Bohlin, 1972).

On Mars, the number of hydrogen atoms in the exosphere may vary due either to changes in the rate of escape of atomic hydrogen through thermal evaporation from the exosphere or to changes in the rate of supply of atomic hydrogen to the exosphere. Since an increase in the thermospheric temperature would lead to an increase in escape rate, the hydrogen atom density should decrease with an increase in thermospheric temperature. The supply of atomic hydrogen to the exosphere may be controlled by the rate of dissociation of a hydrogen-bearing molecule, most likely either water vapor or molecular hydrogen. The rate of dissociation, in turn, may vary either because of changes in the dissociating solar flux or in the supply of the hydrogen-bearing molecule to the upper atmosphere. For example, the release of water vapor

into the lower atmosphere of Mars may vary seasonally or its transport into the upper atmosphere may be regulated by the thermal structure of the atmosphere. Finally, since the flux of the solar Lyman alpha line does vary with the 27-day rotation of the sun, there should be variations in the Mars Lyman alpha airglow. The 20% variation that has been observed in the Mariner 9 ultraviolet observations is moderate compared with the variation of the solar Lyman alpha flux that has been reported from OSO-5 observations (Blamont and Vidal-Madjar, 1971).

What is most striking about the Mariner 9 Lyman alpha observations is not their variations, but that the observed intensities are as constant as they are. Previous to the Mariner 9 observations, it was anticipated that there might be large variations in the amount of atomic hydrogen in the Mars atmosphere (Barth, 1969; Hord *et al.*, 1970). During November and December 1971 there was a planetwide dust storm on Mars (Masursky *et al.*, 1972). The solar ultraviolet radiation capable of photodissociating water vapor was not able to penetrate to the lower atmosphere. During this same period the temperature structure of the atmosphere changed radically with the higher levels of the atmosphere becoming warmer (Hanel *et al.*, 1972; Kliore *et al.*, 1972). There were strong winds which, in blowing over the extreme elevation variations in the topography (Hord *et al.*, 1972), might have been expected to enhance mixing into the upper atmosphere. During the first 120 days of Mariner 9 observations it was summer in the southern hemisphere and the polar cap became progressively smaller until only a remnant remained (Masursky *et al.*, 1972). While these dramatic climatic changes were occurring in the lower atmosphere, the observed rate of escape of atomic hydrogen from the exosphere remained comparatively constant. These observations suggest that there is a large buffer keeping the supply of atomic hydrogen to the exosphere relatively constant while dramatic variations are taking place in the lower atmosphere of Mars.

ACKNOWLEDGMENTS

This work was supported by the National Aeronautics and Space Administration.

REFERENCES

- ANDERSON, D. E., JR., AND HORD, C. W. (1971). Mariner 6 and 7 ultraviolet spectrometer experiment: analysis of hydrogen Lyman alpha data. *J. Geophys. Res.* **76**, 6666-6673.
- BARKER, E. S. (1972). Detection of O₂ in the Martian atmosphere with the echelle-coude scanner of the 107-inch telescope. *Bull. Amer. Astron. Soc.*, **4**, 371.
- BARTH, C. A. (1969). Planetary ultraviolet spectroscopy. *Appl. Opt.* **8**, 1295-1304.
- BARTH, C. A., HORD, C. W., PEARCE, J. B., KELLY, K. K., ANDERSON, G. P., AND STEWART, A. I. (1971). Mariner 6 and 7 ultraviolet spectrometer experiment: upper atmosphere data. *J. Geophys. Res.* **76**, 2213-2227.
- BARTH, C. A., HORD, C. W., STEWART, A. I., AND LANE, A. L. (1972). Mariner 9 ultraviolet spectrometer experiment: initial results. *Science* **175**, 309-312.
- BLAMONT, J. E., AND VIDAL-MADJAR, A. (1971). Monitoring of the Lyman-alpha emission line of the sun during the year 1969. *J. Geophys. Res.* **76**, 4311-4324.
- BRUNER, E. C., JR., AND RENSE, W. A. (1969). Rocket observations of profiles of solar ultraviolet emission lines. *Astrophys. J.* **157**, 417-424.
- DALGARNO, A., DEGGES, T. C., AND STEWART, A. I. (1970). Mariner 6: origin of Mars ionized carbon dioxide ultraviolet spectrum. *Science* **167**, 1490-1491.
- DESSLER, A. J. (1968). Ionizing plasma flux in the Martian upper atmosphere. In "The atmospheres of Venus and Mars." pp. 241-250 (J. C. Brandt and M. B. McElroy, Eds.). Gordon and Breach, New York.
- FEHSENFELD, F. C., DUNKIN, D. B., AND FERGUSON, E. E. (1970). Rate constants for the reaction of CO₂⁺ with O, O₂ and NO; N₂⁺ with O and NO; and O₂⁺ with NO. *Planet Space Sci.* **18**, 1267-1269.
- FJELDBO, G. A., KLILORE, A. J., AND SEIDEL, B. (1970). The Mariner 1969 occultation measurements of the upper atmosphere of Mars. *Radio Sci.* **5**, 381-386.
- HANEL, R. A., CONRATH, B. J., HOVIS, W. A., KUNDE, V. G., LOWMAN, P. D., PEARL, J. C., PRABHAKARA, C., AND SCHLACHMAN, B. (1972). Infrared spectroscopy experiment on the Mariner 9 mission: preliminary results. *Science* **175**, 305-308.

- HORD, C. W., BARTH, C. A., AND PEARCE, J. B. (1970). Ultraviolet spectroscopy experiment for Mariner Mars 1971. *Icarus* **12**, 63-77.
- HORD, C. W., BARTH, C. A., STEWART, A. I., AND LANE, A. L. (1972). Mariner 9 ultraviolet spectrometer experiment: photometry and topography of Mars. *Icarus* **17**, 443-456.
- HUNTEN, D. M., AND McELROY, M. B. (1970). Production and escape of hydrogen on Mars. *J. Geophys. Res.* **75**, 5989-6001.
- KAPLAN, L. D., CONNES, J., AND CONNES, P. (1969). Carbon monoxide in the Martian atmosphere. *Astrophys. J.* **157**, L187-192.
- KLIORE, A. J., CAIN, D. L., FJELDBO, G., AND SEIDEL, B. L. (1972). Mariner 9 s-band Martian occultation experiment: initial results on the atmosphere and topography of Mars. *Science* **175**, 313-317.
- KOCKARTS, G., AND NICOLET, M. (1962). Le probleme aeronomique de l'helium et de l'hydrogene neutres. *Ann. Geophys.* **18**, 269-290.
- LANE, A. L., BARTH, C. A., HORD, C. W., AND STEWART, A. I. (1972). Mariner 9 ultraviolet spectrometer experiment: observations of ozone on Mars. *Icarus*, in press.
- MASURSKY, H., BATSON, R. M., McCAULEY, J. F., SODERBLOM, L. A., WILDEY, R. L., CARR, M. H., MILTON, D. J., WILHELMS, D. E., SMITH, B. A., KIRBY, T. B., ROBINSON, J. C., LEOVY, C. B., BRIGGS, G. A., DUXBURY, T. C., ACTON, C. H., JR., MURRAY, B. C., CUTTS, J. A., SHARP, R. P., SMITH, S., LEIGHTON, R. B., SAGAN, C., VEVERKA, J., NOLAND, M., LEDERBERG, J., LEVINTHAL, E., POLLACK, J. B., MOORE, J. T., JR., HARTMANN, W. K., SHIPLEY, E. N., VAUCOULEURS, G. DE, AND DAVIES, M. E. (1972). Mariner 9 television reconnaissance of Mars and its satellites: preliminary results. *Science* **175**, 294-305.
- McCONNELL, J. C., AND McELROY, M. B. (1970). Excitation processes for Martian dayglow. *J. Geophys. Res.* **75**, 7290-7293.
- McELROY, M. B. (1972). Mars: an evolving atmosphere. *Science* **175**, 443-445.
- MEIER, R. R. (1969). Temporal variations of solar Lyman alpha. *J. Geophys. Res.* **74**, 6487-6493.
- STEWART, A. I. (1972). Mariner 6 and 7 ultraviolet spectrometer experiment: implications of CO₂⁺, CO and O airglow. *J. Geophys. Res.* **77**, 54-68.
- STEWART, A. I., BARTH, C. A., HORD, C. W., AND LANE, A. L. (1972). Mariner 9 ultraviolet spectrometer experiment: structure of Mars' upper atmosphere. *Icarus* **17**, 469-474.
- STRICKLAND, D. J., THOMAS, G. E., AND SPARKS, P. R. (1972). Mariner 6 and 7 ultraviolet spectrometer experiment: analysis of the OI 1304 Å and 1356 Å emissions. *J. Geophys. Res.*, **77**, 4052.
- THOMAS, G. E. (1971). Neutral composition of the upper atmosphere of Mars as determined from the Mariner uv spectrometer experiments. *J. Atmos. Sci.* **28**, 859-868.
- THOMAS, G. E., AND BOHLIN, R. C. (1972). Lyman alpha measurements of neutral hydrogen in the outer geocorona and in interplanetary space. *J. Geophys. Res.* **77**, 2752.
- TRAUB, W. A., AND CARLETON, N. P. (1972). Observations of O₂ on Mars and Venus. *Bull. Amer. Astron. Soc.*, **4**, 371.

DISCUSSION

MAROV: What is the background sky brightness for Lyman α and oxygen?

BARTH: About 300 Rayleighs for $\text{L}\alpha$; there was no detection of atomic oxygen (corresponding to a brightness less than 10 Rayleighs).

MAROV: We found about 800 Rayleighs for Lyman α and from 3 to 5 Rayleighs for atomic oxygen. Is it possible to explain the height distribution of Lyman α in terms of a vertical distribution of hydrogen atoms?

BARTH: Yes, dissociation of H₂O might produce sufficient atomic hydrogen.

MAROV: Is it possible, though, to explain the mixing ratio of atomic hydrogen (1×10^{-6}) required?

BARTH: Yes; the problem is to explain the small amount of atomic oxygen seen.

WEILL: Do you see the 1356 Å line?

BARTH: Yes, the 1356 Å line is present (it arises from photo-dissociation of CO₂).