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10. Predawn air temperatures measured 167 cm above the surface during the first day after landing as part of the lander meteorology experiment show excellent agreement with the predawn T_{11} values.
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17. The two Viking IRTM experiments represent a fourfold increase in the total number of thermal detectors flown to other planets. Their success is the result of the individual efforts of a large number of people during design, fabrication, and the complex flight operations of this instrument. The prolonged efforts of Mike Agabra, Jack Engel, Howard Eyerly, Claude Michaux, Richard Ruiz, and Don Schofield are representative of this group. The massive data reduction system is a tribute to and from Bob Mehlman, John Gieselman, and Elliot Goldyn. We hope all involved take satisfaction from this evidence of their effort. Supported by Jet Propulsion Laboratory contract 952988 to the University of California.

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Composition and Structure of the Martian Atmosphere: Preliminary Results from Viking 1

Abstract. *Results from the aeroshell-mounted neutral mass spectrometer on Viking 1 indicate that the upper atmosphere of Mars is composed mainly of CO_2 with trace quantities of N_2, Ar, O, O_2, and CO. The mixing ratios by volume relative to CO_2 for N_2, Ar, and O_2 are about 0.06, 0.015, and 0.003, respectively, at an altitude near 135 kilometers. Molecular oxygen (O_2^+) is a major component of the ionosphere according to results from the retarding potential analyzer. The atmosphere between 140 and 200 kilometers has an average temperature of about 180° ± 20°K. Atmospheric pressure at the landing site for Viking 1 was 7.3 millibars at an air temperature of 241°K. The descent data are consistent with the view that CO_2 should be the major constituent of the lower martian atmosphere.*

The Viking spacecraft which landed on Mars on 20 July 1976, about 4 hours after local noon, included a set of instruments which measured the physical and chemical properties of the martian atmosphere during entry. The upper atmosphere, above about 100 km, was sampled with a mass spectrometer sensitive to neutral gases in the mass range 1 to 50. Properties of the martian ionosphere were determined with a planar retarding potential analyzer (RPA) designed to provide information on the temperature, composition, and concentration of atmospheric ions. The RPA, which also measured electron energy spectra, was expected in addition to clarify the nature of the interaction between Mars and the external solar wind. The RPA and the upper atmospheric mass spectrometer (UAMS) were mounted on the spacecraft aeroshell. Pressure, temperature, and acceleration sensors gave data on the structure of the atmosphere below 100 km. These results, combined with information from the spacecraft's gyroscopes and radar altimeter, allow one to determine the variation of atmospheric density, pressure, temperature, and winds over an extensive height range for the lower atmosphere.

In this report we present a preliminary account of the results obtained from the various entry science experiments. More detailed accounts of the instruments are given elsewhere (*1*). The UAMS employed an open ion source mounted in such a manner as to allow ambient atmosphere to enter the instrument directly, an important design feature which permits a qualitative measurement for reactive gases such as O. The concentration of chemically inert species may be determined with some confidence from laboratory calibrations obtained prior to flight. The instrument was also exposed to a high-speed molecular beam designed to simulate motion of the spacecraft through the martian atmosphere. These data allow one to establish a quantitative relation between measured quantities and ambient atmospheric densities (*2*).

A spare instrument, identical to the flight instrument, was set up in the laboratory to facilitate a number of studies not possible in preflight tests. Figure 1 produces a variety of spectra obtained with pure CO_2, CO_2 with 2 percent Ar, and CO_2 with 5 percent N_2. The mass peaks at 44, 28, 22, 16, and 12 in Fig. 1a correspond to CO_2^+, CO^+, CO_2^{2+}, O^+, and C^+, respectively. The incident electrons in Fig. 1, and for the martian spectra shown in the other figures, have energies equal to 75 ev. Figure 1a also indicates mass peaks at 46, 45, 30, 29, 23, 22.5, and 13, due to $(^{12}C^{16}O^{18}O)^+$, $(^{13}C^{16}O^{16}O)^+$, $(^{12}C^{18}O)^+$, $(^{13}C^{16}O)^+$, $(^{12}C^{16}O^{18}O)^{2+}$, $(^{13}C^{16}O^{16}O)^{2+}$, and $(^{13}C)^+$. Mass peaks at 32 and 14 are associated with a small quantity of O_2^+ and CO^{2+} formed during the ionization of CO_2. Peaks at 17 and 18 are due to residual concentrations of H_2O present as an impurity in the instrument. Addition of Ar (Fig. 1b) gives rise to peaks at 40 and 20. The peak at 28 is approximately doubled by addition of 5 percent N_2 (Fig. 1c), and the presence of N_2 is further confirmed by the peak at mass 14 due to N^+ and $(N_2)^{2+}$.

Figure 2 gives a sample spectrum for Mars obtained at an altitude of approximately 135 km above the martian surface. Prominent peaks at masses 40 and 20 show clear evidence for Ar. The mixing ratio for the gas at this altitude, relative to CO_2, is approximately 0.015 by volume, in major disagreement with an indirect measurement of Ar inferred from data obtained by the Soviet probe Mars 6. Istomin and Grechnev (*3*) reported a mixing ratio of 0.54 ± 0.2 for an inert constituent of the martian atmosphere which they attributed to Ar. The mixing ratio of ^{40}Ar in the lower martian atmosphere cannot be this high and must lie somewhere in the range 0.01 to 0.02.

The peak at mass 28 in Fig. 2 contains contributions from CO^+ formed by the ionization of CO_2 and CO, in addition to N_2^+ formed by the ionization of N_2. The peak at mass 14 is composed primarily of N^+ and $(N_2)^{2+}$ from N_2, although it includes also a small contribution from $(CO)^{2+}$ formed by the ionization of CO_2 and CO. The data in Fig. 2 indicate a mixing ratio of N_2 relative to CO_2 of about 0.06. Much higher mixing ratios were detected at higher altitude, as would be expected as a result of the diffusive separation of the lighter gas, N_2. A preliminary attempt to extrapolate the present data to lower altitude suggests a mixing ratio, N_2 to CO_2, of between 0.02 and 0.03 for the bulk atmosphere, consistent with an upper limit for this parameter imposed earlier (*4*) based on analysis of the ultraviolet day glow spectra measured by Mariner 6 and Mariner 7 (*5*).

The peak at mass 32 is due primarily to O_2 and suggests a mixing ratio, O_2 to

CO_2, of about 0.003 near 135 km. The peak at mass 16 indicates a detectable concentration of O. More extensive analysis of the data should permit a quantitative statement on the abundance of atmospheric O and should also provide useful information on the concentration of CO. The relative abundances of oxygen and carbon isotopes, $^{18}O/^{16}O$ and $^{13}C/^{12}C$, appear to lie close to their terrestrial values. Peaks at masses 16 and 17 are due primarily to terrestrial H_2O released from the surface of the ion source after bombardment of the surface by ambient martian gas. The ratio $^{36}Ar/^{40}Ar$ cannot exceed the value for this parameter in the terrestrial atmosphere, and may be much lower.

The distribution of CO_2, Ar, N_2, and O_2 with altitude, as inferred from some 20 spectra taken over the height range from 140 to 190 km suggests an average temperature near 180°K, with an uncertainty of about ± 20°K. The height distribution of major gases shows a clear indication of the influence of diffusive separation and indicates that mass mixing processes in the martian atmosphere cannot play a major role for altitudes above about 140 km.

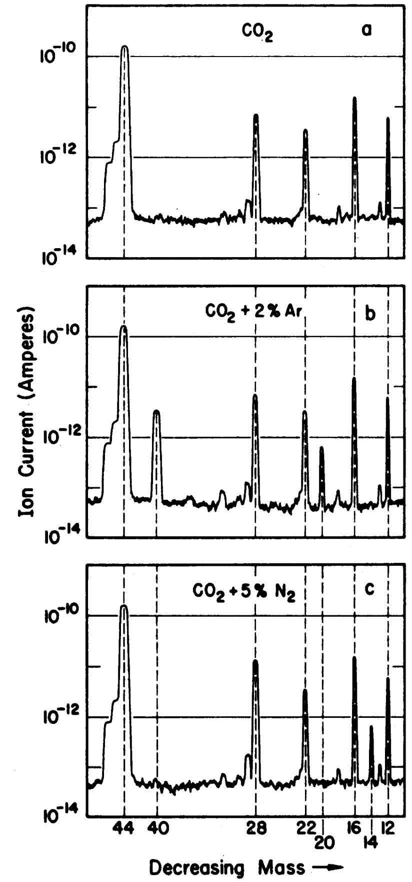
Figure 3 shows a sample of data recorded by the RPA at an altitude of about 130 km. The smooth curve through the observed points was obtained from a least squares fit to the data (*6*). The analysis indicates that O_2^+ is the major constituent of the martian ionosphere at this altitude. Carbon dioxide, CO_2^+, is less abundant by about a factor of 9, with an uncertainty of about ± 5 percent. The ions exhibit a temperature of about 160°K, and the uncertainty in temperature is also estimated to be about ± 5 percent. The temperature derived from the RPA data is consistent with the value noted above from a study of height profiles measured by the UAMS.

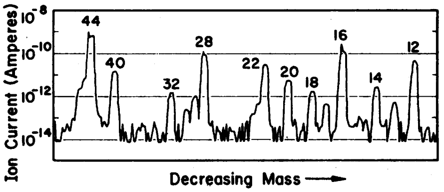
The direct measurement of O_2^+ as a major component of the martian ionosphere is an important new result. It lends support to earlier theoretical analyses of the martian ionosphere (*7*) which argued the importance of the reaction

$$CO_2^+ + O \rightarrow CO + O_2^+ \qquad (1)$$

as a means of converting the primary photoion CO_2^+ to the more stable form O_2^+. It suggests (*8*) a mixing ratio, O to CO_2, of about 0.03, with an uncertainty of about 50 percent, if we use the rate constant for Eq. 1 measured by Fehsenfeld *et al.* (*9*). The RPA measurement of ion composition also supports the view (*10*) that recombination fo O_2^+ can provide an important source of energetic oxygen atoms which may escape to space from upper regions of the martian atmosphere.

The measurements in the lower atmosphere indicate a surface pressure at the landing site of 7.3 mbar, with an atmospheric temperature at ground level of 241°K and a subadiabatic lapse rate for temperatures near the ground of 3.7°K km^{-1}. The atmospheric density, obtained from an analysis of the descent velocity of the payload during the parachute phase of the entry sequence, is about 0.0136 kg m^{-3} at an altitude of about 2.7 km,





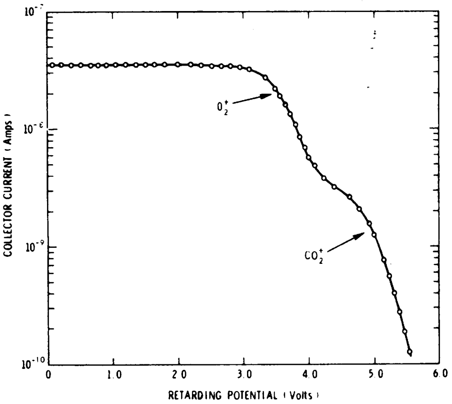
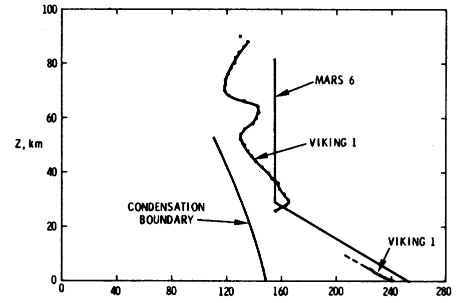


Fig. 1 (left). Mass spectra obtained in laboratory with instrument similar to that carried on Viking 1 lander. (a) Pure CO_2; (b) CO_2 containing 2 percent Ar; (c) CO_2 containing 5 percent N_2. Fig. 2 (top right). Mass spectrum obtained at an altitude of 135 km by the UAMS during the descent of Viking 1 lander to the surface of Mars on 20 July 1976. The spectrum shows the presence of CO_2, Ar, N_2, O_2, and O. A detailed analysis is required to establish the presence of CO. Also seen are peaks associated with isotopes. Fig. 3 (bottom right). Ion retarding potential curve recorded by the RPA near an altitude of 130 km during entry at a solar zenith angle of approximately 44°. The solid line theoretical curve through the data points corresponds to T_i = 158°K, $n(O_2^+) = 9.5 \times 10^4$ cm^{-3} and $n(CO_2^+) = 1.1 \times 10^4$ cm^{-3}.



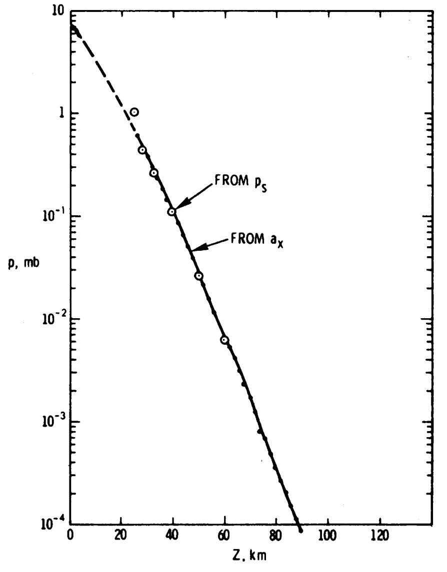


Fig. 4 (left). First analysis of the temperature profile, for the deceleration data and the direct sensing below 3.5 km. Fig. 5 (right). First analysis of the pressure profile from the acceleration data (a_x), stagnation pressure sensing (p_s), and parachute phase direct sensing (heavy dots below 3.5 km). The data are self-consistent.

consistent with the view that the atmosphere is composed mainly of CO_2.

Temperatures in the middle atmosphere, at altitudes Z from 25 to 90 km (Fig. 4), ranged from 120° to 165°K, with local peaks at 64 and 30 km, and would appear to join smoothly with the mass spectrometer temperatures above 140 km. At the time of entry, the CO_2 condensation boundary was about 20°K below atmospheric temperatures.

The atmospheric pressure profile to 90 km is shown in Fig. 5. The middle atmosphere data extend smoothly into the directly sensed data below 3.5 km. Ambient densities (not shown) were likewise defined over five decades, and at altitudes above 35 km were 2 to 5 times greater than the mean model to which the Viking lander was designed. At touchdown, however, density was near the pre-Viking expectation.

The pressure data indicate that the landing site is about 2.9 km below the mean martian surface, if we take an average surface pressure for the martian atmosphere equal to 6.1 mbar. The accelerometer data, however, indicate an acceleration due to gravity at the landing site of 3.7189 ± 0.0006 m sec^{-2}, which implies a planetocentric distance at touchdown of 3389.8 ± 0.03 km (*11*), while the radio science data (*12*) indicate a radius of 3389.5 ± 0.3 km. These results may be compared to the value predicted from the mean ellipsoid equation given by Standish (*13*), 3391.51 km, and would imply a terrain elevation at the landing site of -1.7 to -2.0 km, and a mean surface pressure of 6.6 to 6.7 mbar.

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Preliminary Meteorological Results on Mars from the Viking 1 Lander

Abstract. *The results from the meteorology instruments on the Viking 1 lander are presented for the first 4 sols of operation. The instruments are working satisfactorily. Temperatures fluctuated from a low of 188°K to an estimated maximum of 244°K. The mean pressure is 7.65 millibars with a diurnal variation of amplitude 0.1 millibar. Wind speeds averaged over several minutes have ranged from essentially calm to 9 meters per second. Wind directions have exhibited a remarkable regularity which may be associated with nocturnal downslope winds and gravitational oscillations, or to tidal effects of the diurnal pressure wave, or to both.*

The meteorology instruments and system on the Viking lander have been described (*1*), and only a brief description suffices here. Two hot film sensors orthogonally oriented in the horizontal plane are used to determine wind speed and direction by measuring the power required to maintain constant overheating with respect to an identical unheated reference sensor. A fourfold ambiguity in wind direction as sensed by this array is resolved by means of a quadrant sensor, which utilizes four thermocouples to sense temperature differences on four sides of a heated vertical rod. This is an application of the classical "wet finger" method of wind determination. This sensor also provides information and wind speed in the Reynolds-number range, in which it is now operating on Mars, and data from both the hot film and quadrant sensors are reduced together to provide best measures of wind speed and direction in the least squares sense. The reference temperature sensor is subject to radiation and conduction errors at the low pressure prevailing on Mars. Accurate temperature measurements are made by means of a set of thermocouples, which are referenced to an internal temperature measured by means of a platinum resistance thermometer. The entire array is mounted on a boom deployed 1.6 m above the surface, and 0.61 m from the nearest part of the lander body. Wind tunnel tests indicate measurement accuracies of at least ± 15 percent for wind speed in excess of 2 m/sec, ± 10° in wind direction and ± 1.5°C in temperature. Tests also indicate that effects of lander interference should not be large, but may have a small effect on flow at azimuths between about 260° and 340° (*2*). In addition, pressure is measured by means of a sensor within the lander body whose accuracy and stability are comparable with the digital resolution, about 0.07 mbar.

Table 1. Average variances for 11-minute modules during the first 5 sols. Night includes the period from 1.5 hours before sunset to 1.5 hours after sunrise; day includes the remainder of the sol.

Time	Variance		
	Temperature (°C)	Wind direction (deg)	Wind speed (m/sec)
Night	0.57	7.6	0.74
Day	2.63	24.5	2.07

All indications are that the entire system is performing nominally. Our confidence in the temperature measurements is based on the comparison between the reference and thermocouple sensors; the differences between them are those expected from radiation and conduction effects. Wind directions and