Table 1 are nine previously identified with optical galaxies (5). Since they are at approximately the same distances from the parent peculiar galaxies as the radio sources in general, there is no reason to believe that the luminous material is traveling with any different velocity than the plasma which emits the radio signals. In particular, the quasars in Table 1 are essentially the same distance as the radio sources and luminous matter and, therefore, must be traveling with spatial velocities of the order of 10^3 km/sec.

Two very approximate direct checks are available. First, M87, the opposite particle to 3C273, is traveling away in our line of sight, relative to the central elliptical NGC 4472, with a velocity of 300 km/sec. Symmetry implies that 3C273 is approaching with this component of velocity in the line of sight. Its true space velocity must be somewhat higher, depending on the projection factor. The second piece of evidence comes from a triplet of peculiar galaxies studied by Zwicky (7). Two ellipticals traveling at +7000 km/sec are seen attached to a spiral traveling at +100 km/sec. It appears now that this spiral is being ejected with a velocity of about 7×10^3 km/sec. Order of magnitude limits to the ejection velocities of the radio sources then seem to lie between 10^2 and 10^4 km/sec.

The nature of the large red shifts observed in the quasars then remains unexplained. We have shown here that neither cosmological recessional velocities nor large Doppler velocities can be the answer (the latter is also doubtful because of the failure to observe blue shifts). As discussed by Greenstein and Schmidt (8), line shifts in the gravitational field of a very dense body should be the only remaining possibility. I would like to add one other possibility: that of high collapse velocity of material toward the center of these very compact objects. The region radiating the emission lines would have to be opaque to obscure the blue shifts from the back side. A hotter surface below should produce absorption lines on the red side of the emission lines (reverse P Cygni effect). That surface might, however, be red-shifted out of visibility—or possibly the emitting material might actually form a hollow shell collapsing from a larger spherical shell distribution. If only parts of that shell were luminous at a given time, fairly narrow emission lines could possibly result. Since there are objections to both the gravitational and collapse explanations of the large red shifts, however, the true explanation may lie in a direction so far not considered.

The results so far open up a number of possibilities. Among them are: (i) If it is possible to observe large spectral red shifts which are noncosmological, then the velocity-distance relationship for ostensibly normal galaxies should be regarded with slightly more caution. (ii) If material in galactic amounts can be ejected from other galaxies, the possibility is raised that certain kinds of galaxies, particularly spiral galaxies, can be much younger than other kinds of galaxies. (iii) If ejection from a center can take place more slowly, with differential rotation, then spiral galaxies themselves may be a manifestation of this phenomenon. (iv) Very small, compact dwarf galaxies with emission lines recently discovered (9) appear to be characteristically double. It may be possible to show that these also represent fairly recent ejections from nearby galaxies. (v) The cause and mechanism of the ejection of material from galaxies becomes an even deeper puzzle which may be connected with the formation of galaxies. (vi) The ejection of material into intergalactic space must affect the composition of that space. If the ejected plasma is ultimately controlled by the conditions it finds there, then we have experiments which connect the galaxies with the conditions in the space in which they are imbedded.

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25 February 1966

Mars: Upper Atmosphere

Abstract. *The thermal structure of the upper atmosphere of Mars has been theoretically investigated. The exospheric temperature, for a pure CO_2 model atmosphere, lies between 400° and 700°K. The origin of the Martian atmosphere is discussed in the light of these results.*

Recent spectroscopic measurements (1) and results of the Mariner IV occultation experiment (2) indicate that the atmosphere of Mars may be mainly composed of CO_2 with a total atmospheric pressure at the surface of 5 to 10 mb. Using this model we have calculated the thermal structure of the upper atmosphere. The results indicate that the exospheric temperature of Mars may be 550° ± 150°K (Fig. 1). The temperature profile is consistent with the temperatures deduced from the Mariner IV occultation experiment.

The method of computation and the basic assumptions made for these calculations are as follows: It is assumed that the average surface temperature is 200°K, and that the lower atmosphere, up to 80 km, is in radiative equilibrium; the temperature profile for this region has been calculated from the method described by Prabhakara and Hogan (3). At this level the dissociation of CO_2 by solar ultraviolet radiation becomes effective; we assume that, above 80 km, the dissociation products of CO_2, CO and O, are in diffusive equilibrium.

The temperature structure in the thermosphere and exosphere is calculated by the method described in detail by Chamberlain (4), McElroy, L'Ecuyer, and Chamberlain (5), and Rasool, Gross, and McGovern (6). The input of energy in this region is mainly in the far ultraviolet, through the ionization of atomic oxygen, while the emission is by CO_2 and CO. The presence of CO in the upper atmosphere is extremely effective in reducing the exospheric temperature, mainly because the emission is proportional to the square of the temperature T (5). For this reason the exospheric temperature (T_{ex}) on Mars is as low as about 550°K, whereas T_{ex} for Earth is approximately 1500°K. The large uncertainty of ±150°K in the value of T_{ex} for Mars (Fig. 1) results from the uncertainties in the value of the solar flux in the extreme ultraviolet, the exact fraction of solar energy that goes into heating, and also the altitude at which CO radiation becomes effective.

Our results differ considerably from the temperature profile for Mars recently published by Johnson (*7*) in which the upper atmosphere is isothermal at 85°K. Johnson's value for the temperature is derived from the observation of Mariner IV's occultation experiment that the electron-density scale height above 125 km on Mars is 25 km. The neutral gas-density scale height will then be 12.5 km. If the principal ion is O^+, then for an isothermal atmosphere the temperature should be 85°K. However, if there is a positive temperature gradient, then the actual scale height in the atmosphere can be much larger than the isothermal scale height. For an atmosphere in hydrostatic equilibrium, the two scale heights, H and H' (actual and isothermal), are related by the following expression:

$$H = \frac{H'}{1 - \frac{H'}{T}\frac{dT}{dz}} \qquad (1)$$

Johnson assumes $dT/dz = 0$ and therefore infers that $H = H' = 25$ km. But, as seen from Eq. 1, depending on the temperature gradient and the actual temperature of that region, a number of solutions for H are possible. If, for example, we assume that, in the atmospheric region explored by Mariner IV's occultation experiment (55°S, winter),

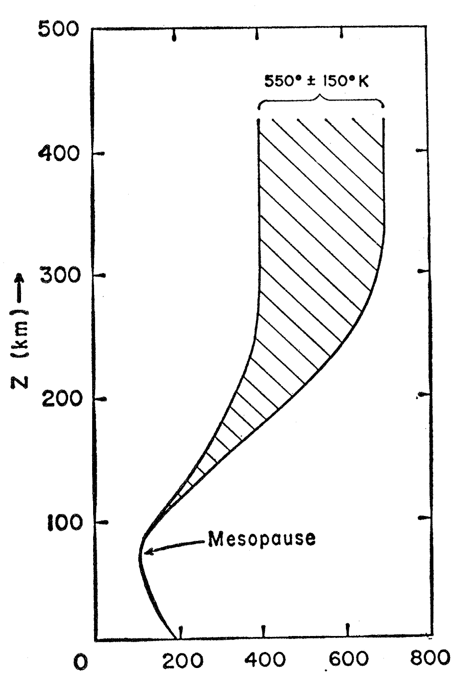

Fig. 1. Vertical distribution of temperature in the atmosphere of Mars. The range of uncertainty in the temperature of the upper atmosphere, ± 150°K, is shown as the hatched area. An atmosphere of pure CO_2 with a surface pressure of 8 mb was assumed.

$(dT/dz)_{125\ \text{km}} = 2°\text{K/km}$ (Fig. 1) and $T_{125\ \text{km}} = 150°\text{K}$, then for $H' = 25$ km, $H = 37.5$ km. This scale height will be consistent with an atomic oxygen atmosphere at $T \sim 150°\text{K}$.

The calculated temperature at 125 km altitude (Fig. 1) is slightly higher than 150°K, mainly because our model is an average for the whole planet, while the results of the occultation experiment concern the Martian atmosphere at 55°S, winter hemisphere, in the local afternoon.

It therefore seems clear that Johnson's model is based on only one of several ways in which measurements of electron-density scale height can be interpreted. It has the further disadvantage of putting stringent requirements on the energetics of the thermosphere. An isothermal thermosphere implies that, at each height, the amount of absorption of ultraviolet radiation *exactly equals* the emission by CO_2 and CO at that height. It is difficult to see how this condition will be met at all times and at all points on the planet.

Our result has some implications regarding the origin of the observed CO_2 on Mars.

At $T_{ex} = 550°\text{K}$, both H_2 and He will be lost rapidly, but O will not escape. The present atmosphere of Mars may therefore be a remnant of a heavier primitive atmosphere which once had a composition similar to that observed today on Jupiter—that is, with large quantities of H_2 and He and small amounts of CH_4, NH_3, and probably H_2O. Once H_2 and He have escaped, the residual atmosphere will be composed mainly of CO_2 with relatively small but substantial amounts of Ne and N_2 (*6*). If this is the process by which the atmosphere of Mars has evolved, then the exospheric temperature on Mars should be greater than the escape temperature for He, but less than the escape temperature for O—that is, $1100° > T_{ex} > 275°\text{K}$. Also, if the total amount of CO_2 in the Martian atmosphere is 5 mb, then from the cosmic abundance table it follows that there must also be at least 2 mb of Ne and 1 mb of N_2 in the atmosphere (*8*). Both these gases are difficult to observe from Earth, and their identification on Mars must therefore await *in situ* exploration.

Johnson has proposed the alternative hypothesis that the present atmosphere of Mars is a result of outgassing from the interior. This hypothesis implies that the atmospheric pressure on Mars was never greater than the present value of about 10 mb and that there must be large quantities of frozen water under the surface of Mars (*7*).

Only the future fly-bys and landers on Mars will be able to test these conjectures by measuring the exospheric temperature, searching for rare gases by mass spectrometer, and examining the surface properties of the planet. These questions regarding the origin and evolution of the Martian atmosphere are not only of profound scientific interest, but are also of the greatest general and philosophical importance because they relate to the primitive physical environment of the planets and the circumstances under which life may have developed on the earth and on other bodies in the solar system.

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9. One of us (W.E.M.) was supported by NASA grant N.S.G. 499.

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Middle Devonian Lunar Month

Abstract. *Simple dynamical calculations regarding the number of lunar months in the Middle Devonian year differ slightly from results obtained from periodicities found in the breeding of corals.*

On the basis of counts of fine growth ridges on Middle Devonian corals, Scrutton has estimated that the Middle Devonian year contained 13 lunar months of 30½ days each (*1*). A check