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The Atmosphere of Mars*

Francis S. Johnson
Southwest Center for Advanced Studies
Dallas, Texas

Abstract

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Much new information has become available in recent years on the Martian atmosphere. Mariner IV data have shown that the surface pressure is below ten millibars, a result that is not inconsistent with the most recent spectroscopic studies. If the Mariner IV ionospheric data are interpreted in terms of an F2 peak, the atmosphere must be very cold at all levels and the exospheric temperature must be near 85°K. This result is in disagreement with studies of radiative equilibrium temperatures, which indicate a relatively warm exosphere, the temperature being in the vicinity of 400°K. As a consequence of this inconsistency and others of a similar nature, there is still a wide range of speculation concerning the properties of the Martian atmosphere. These inconsistencies will probably be resolved only after more detailed observations have been made in planetary probes, such as the distribution of resonance scattering of sunlight by atomic oxygen.

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Mariner IV data (Kliore et al., 1965a) show that the surface pressure on Mars in quite low, less than 10 mb, and that the atmosphere consists mainly of carbon dioxide. Johnson (1965) has argued that the concept that the earth's atmosphere has arisen from within the planet, if applied to Mars, predicts an atmospheric composition that is in agreement with the observations.

On earth, the two most plentiful gases that have been released from the earth's interior are water vapor and carbon dioxide. About 3×10^5 g/cm^2 water vapor have been released, and this has gone mainly into the formation of the oceans. About 2×10^4 g/cm^2 carbon dioxide have been released, and this has gone mainly into carbonate deposits through chemical processes that depend on the presence of water. The next most plentiful gas has probably been nitrogen, of which about 10^3 g/cm^2 have been released; however, this is a constituent that is sufficiently inert so that it can accumulate in the atmosphere, and it now makes up the bulk of the atmosphere. Oxygen has arisen through secondary processes, initially by photochemical decomposition of water vapor, but predominantly through photosynthesis after life on earth became abundant.

The temperature of Mars is so low that most of the water vapor there would accumulate in ice deposits which could then become covered and obscured by dust. Lacking liquid water, the carbon dioxide that has been released from the Martian interior should remain in the atmosphere and make up most of its bulk. The amount of carbon dioxide on Mars is about 20 g/cm^2; this indicates that the amount of gas that has been released from the interior of Mars is only about 10^{-3} that released on earth in terms of mass per unit area. Thus, the water on Mars can be expected to amount to 300 g/cm^2; this should be non-uniformly distributed over the planet in the form of subsurface deposits of ice. Nitrogen in the atmosphere of Mars should be about 1 g/cm^2, and argon only 0.01 g/cm^2, assuming its release on Mars to be comparable in efficiency to that of the other gases.

The ionosphere on Mars was observed at the unexpectedly low altitude of 120 km (Kliore et al., 1965a; 1965b), and the rate of decrease of ionization with altitude was very rapid above the maximum, the scale height being about 25 km. Different interpretations exist with regard to the ionization peak. It has been identified as an F2 peak (Johnson, 1965; Fjelbo et al., 1966), an Fl peak (Donahue, 1966) and an E peak (Chamberlain and McElroy, 1966).

The identification of the ionization maximum as an F2 peak involves the concept that the peak is controlled by downward diffusion of ionization, that the ions are O^+, and that the predominate loss process for ions involves reactions with neutral molecules and occurs mainly below the ionization maximum. The identification of the ions as O^+ rather than heavier ions requires that a very low temperature be associated with the ionosphere, about 85°K above 120 km. The particle concentration at 120 km is estimated on the basis of diffusion theory to be about 10^9 cm^{-3}, which can be reached only if the average temperature up to 120 km is about 130°K. Johnson (1965) proposed the temperature distribution shown in Figure 1 on the basis of this interpretation.

Two difficulties exist with the F2 interpretation discussed above, one involving chemical rate constants and the other radiation balance.

Fehsenfeld et al. (1966) have measured the rate constant for the reaction

$$O^+ + CO_2 \rightarrow O_2^+ + CO$$

and obtained the large value of 10^{-9} $cm^3 sec^{-1}$. A rate constant of this magnitude would convert O^+ ions to O_2^+ ions very rapidly and eliminate any possibility of forming an F2 peak with greater electron concentrations than those existing at the F1 level unless something happens to reduce the CO_2 concentrations. Fjelbo et al. (1966) suggest that a reduction in CO_2 concentration in the F region is brought about by the freezing out of CO_2 by a temperature minimum near 100 km, so that an F2 peak can still exist even with the large rate coefficient measured by Fehsenfeld et al. for removal of O^+ ions.

The second difficulty with the F2 interpretation is that the low temperatures associated with it cannot be reconciled with the thermal balance calculated on the basis of radiative exchange and molecular conductivity. Chamberlain and McElroy (1966) and Gross et al. (1966) indicate that there is an excess of heat input over heat loss in the infrared that requires the temperature in the exosphere to be in the neighborhood of $400^{\circ}K$ so that molecular conductivity can remove the excess heat by downward conduction. With this consideration in mind, Chamberlain and McElroy (1966) interpret the ionization maximum as an E layer, and conclude that, in order to suppress by chemical means the formation of an F region with larger electron concentrations at higher altitudes, the atmosphere must be well mixed up to 190 km. In their treatment, they do not take into account the effects of eddy transport; their conclusion that that atmosphere must be well mixed up to 190 km implies that mixing must proceed more rapidly than molecular diffusion, which would be characterized by a coefficient of about 2 x 10^8 $cm^2 sec^{-1}$ at 190 km if the concentration of neutral particles there had the value which they indicate. If the eddy coefficient were this large, the downward heat transport by eddy motion at 190 km would be about 0.2 erg $cm^{-2} sec^{-1}$, which appears to be larger than the total heat input above that altitude in their model. The interesting conclusion is that, to satisfy their requirement for mixing, a downward heat transport would have to exist that would completely eliminate the high temperature thermosphere that they obtained while ignoring the eddy transport. This seems to invalidate the E region interpretation.

In the earth's atmosphere, eddy heat transport is more important than radiative heat transport in controlling the thermal balance between about 60 and 120 km (Johnson, 1967). The corresponding altitudes on Mars are, of course, not known, but it is reasonable to assume that eddy transport is of comparably great importance in the Martian atmosphere. Eddy transport could produce a temperature minimum such as that involved in Fjelbo et al.'s (1966) interpretation of the Martian atmosphere. The parallel is that eddy transport is the dominant energy exchange mechanism at the mesopause, and probably is primarily responsible for producing the temperature minimum at 80 km in the earth's atmosphere.

Although Chamberlain and McElroy's (1966) interpretation of the Martian ionosphere as an E region may not be correct, their conclusion that there should be a temperature rise at and above the temperature maximum is significant and not likely to be invalidated by the failure to take into account the eddy heat transport, although some doubt remains on this point. Acceptance of the high temperature (~ 400°K) exosphere would invalidate the F2 interpretation for the ionization peak and lead to the requirement for an alternative interpretation. This alternative might be an F1 region with a high temperature exosphere, something that has been suggested by Donahue (1966).

If the ionization peak is an F1 region, the neutral particle concentration at 120 km should be about 4×10^{10} cm^{-3}, assuming that the absorption cross section is about the same as for the earth's F1 region. The ionization scale height above the ionization peak depends on the ionizable constituent; if it were atomic oxygen, a low temperature (~ 85°K) would be indicated, which is not consistent with the high temperature exosphere. It seems more likely that carbon dioxide should be the ionizable constituent, which would indicate a temperature of 235°K, or even higher when the effect of the temperature gradient is taken into account. The particle concentration at 120 km, compared to that at the ground, indicates an average temperature up to 120 km of 150°K. The temperature distribution and particle concentrations calculated by Chamberlain and McElroy can be used as the basis for an F1 model if they are suitably modified. Their results are shown in Figure 2; since they calculated the vertical distribution assuming a molecular weight of 35, whereas a value near 44 seems more likely, a revised altitude scale based on a molecular weight of 44 is shown on the right-hand side of Figure 2, and the scale is adjusted so that the particle concentration at the ionization peak at 120 km is 4×10^{10} cm^{-3}. Also, below 100 km on the revised scale (or 150 km on their original scale), their temperature distribution and the particle concentrations have been adjusted so as to agree with the requirement that the average temperature below 120 km be $150^{o}K$; their original curves are shown dashed. The concentration curve calculated by Chamberlain and McElroy was for a gas mixture consisting of 44% CO_2 and 56% N_2, whereas in the modified view the concentration curve in Figure 2 represents only the CO_2 concentration; greater concentrations of lighter constituents (most likely atomic oxygen) might exist near the top of the diagram.

It is clear from the foregoing that we are faced with choosing between rather divergent views, at least two at present, and possibly more as time goes on. The substantial uncertainties that exist in the interpretation of the Martian ionosphere are not likely to be fully resolved without more data. Especially valuable will be data on the distribution of specifically identified components, for example, the distribution of atomic oxygen by fluorescence scattering. This will give an independent indication of the exospheric temperature and should clearly discriminate between the F1 and F2 theories for the Martian ionosphere.

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Figure Captions

Figure 1. The temperature distribution through the Martian atmosphere based upon an F2 region interpretation for the ionization maximum (Johnson, 1966).

Figure 2. The temperature distribution and total particle concentration in the Martian atmosphere based on (a) an E region interpretation for the ionization maximum (left-hand scale, and dashed curves below 150 km), (b) on F1 region interpretation (right-hand scale, solid curves below 100 km). The curves are based on the calculations of Chamberlain and McElroy (1966) but with a modified altitude scale and further modified below 100 km (right-hand scale) for the F1 interpretation; in the modified form, the concentration curve applies to CO_2, whereas it originally applied to a mixture of 44% CO_2, 56% N_2.

References

Chamberlain, J. W., and M. B. McElroy, "Martian Atmosphere; the Mariner Occultation Experiment," *Science*, *152*, 21-25, 1966.

Donahue, T. M., "The Upper Atmosphere of Mars," 1966.

Fehsenfeld, F. C., E. E. Ferguson, and A. L. Schmetlekopf, "Thermal Energy Ion-Neutral Reaction Rates III. The Measured Rate Constant for the Reaction $O^+(^4S) + CO_2(^1\Sigma) \rightarrow O_2^+(^2\Pi) + CO(^1\Sigma)$," *J. Chem. Phys.*, *44*, 3022-3024, 1966.

Fjelbo, G., W. C. Fjelbo, and V. R. Eshleman, "Models for the Atmosphere of Mars Based on the Mariner IV Occultation Experiment," *J. Geophys. Res.*, *71*, 2307-2316, 1966.

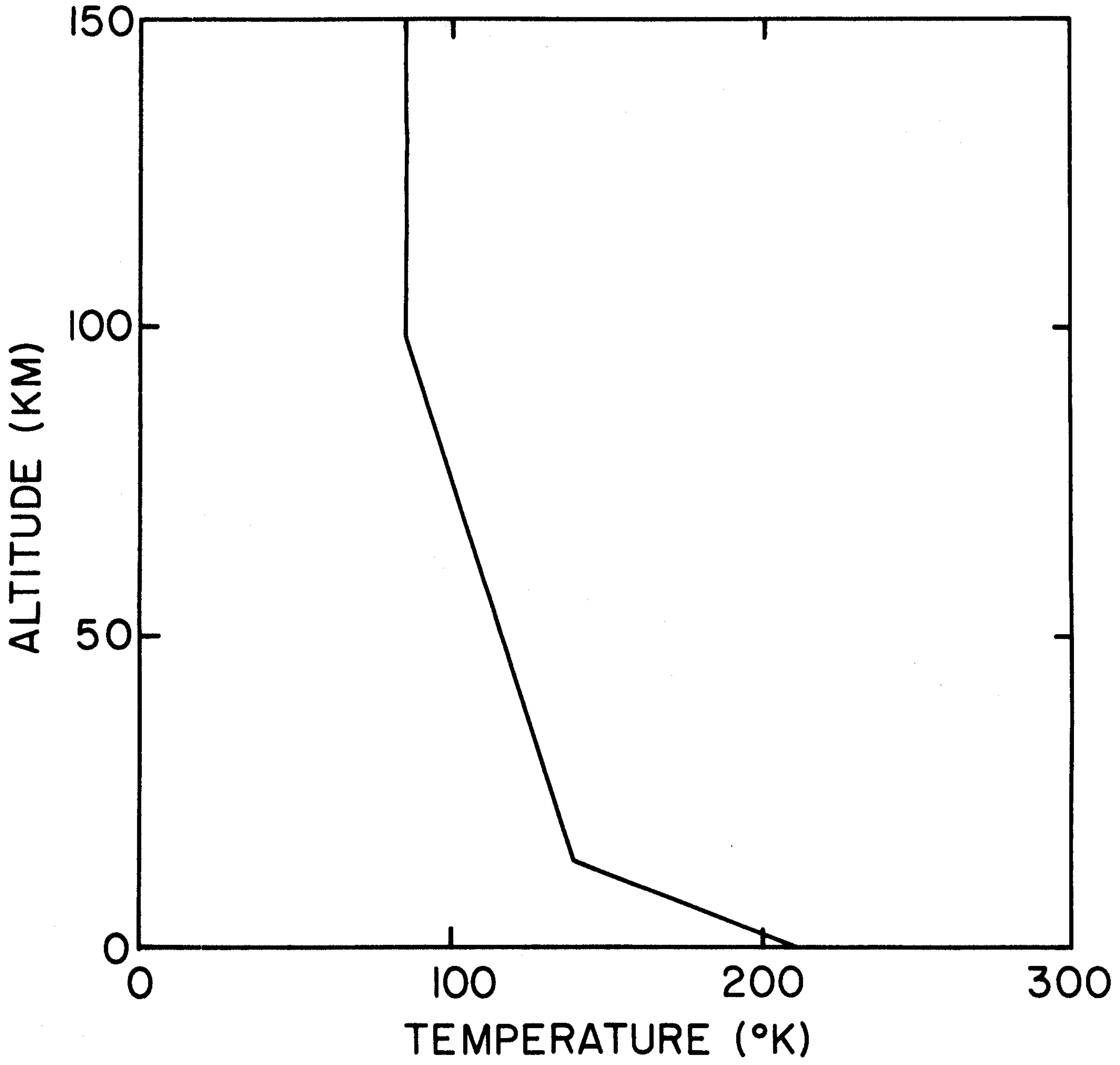
Gross, S. H., W. E. McGovern, and S. I. Rasool, "Mars: Upper Atmosphere," *Science*, *151*, 1216-1221, 1966.

Johnson, F. S., "Atmosphere of Mars," *Science*, *150*, 1445-1448, 1965.

Johnson, F. S., "Turbopause Processes and Effects," COSPAR Seventh International Space Science Symposium, to be published in Space Research, 1967.

Kliore, A., D. C. Cain, G. S. Levy, V. R. Eshleman, G. Fjelbo, F. D. Drake, "Occultation Experiment: Result of the First Direct Measurement of Mar's Atmosphere and Ionosphere," *Science*, *149*, 1243-1248, 1965a.

Kliore, A., D. L. Cain, G. S. Levy, V. R. Eshleman, F. D. Drake, and G. Fjelbo, "The Mariner IV Occultation Experiment," Astronautics, 3 (7), 72-80, 1965b.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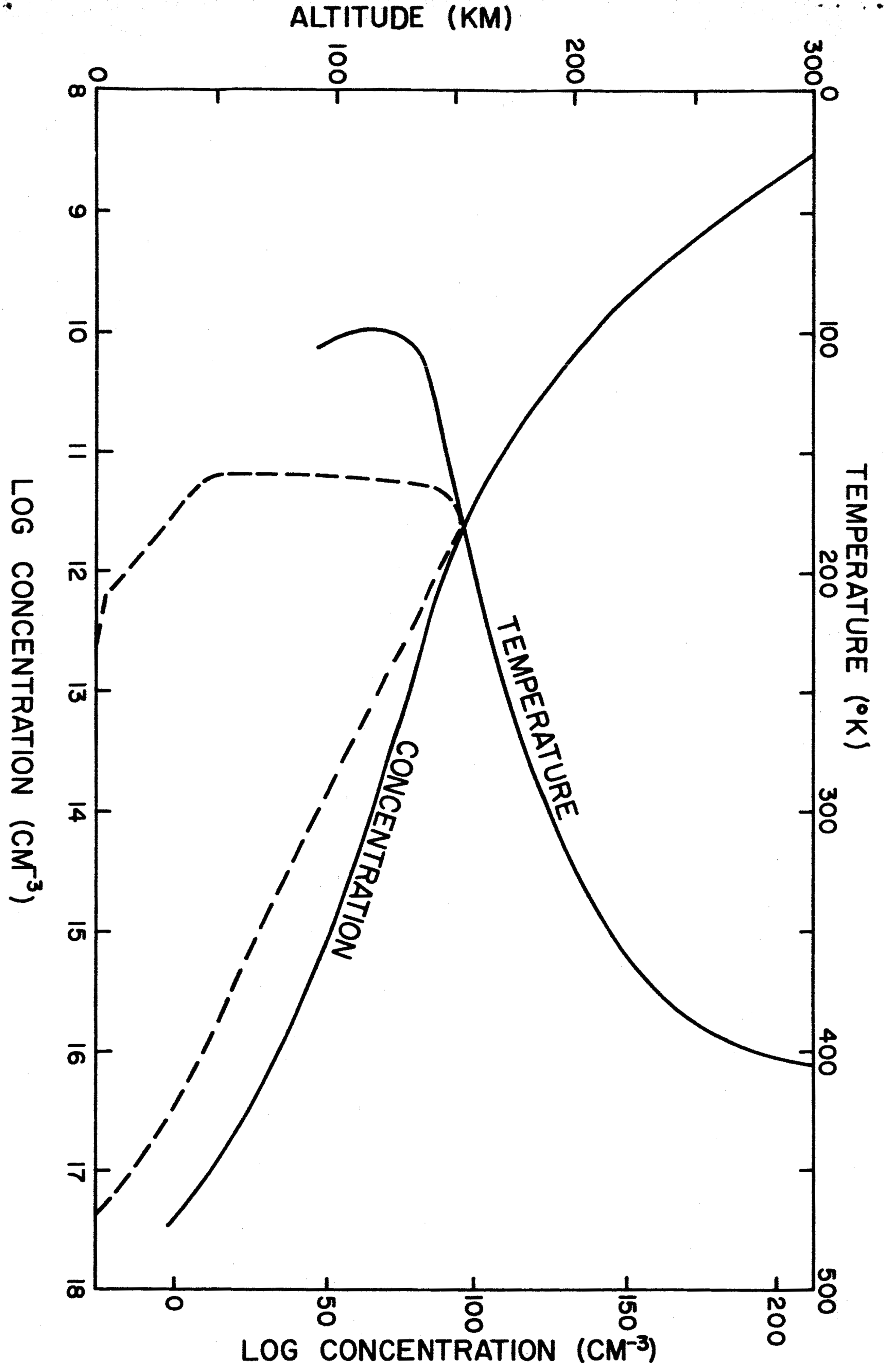ALTITUDE (KM)
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