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2 May 1968

Ice on Venus: Can It Exist?

Libby (*1*) has suggested that the similarity between the amount of CO_2 in the atmosphere of Venus and the total amount of this gas evolved by Earth raises a serious question about the absence of terrestrial amounts of water on Venus. His solution to this dilemma postulates that the water is present in the form of polar ice caps. It is the purpose of this note to call attention to some weaknesses in Libby's arguments.

In order to have extensive ice caps at the poles of Venus, the temperature there must be well below freezing. The available observations do not support this condition. Clark and Kuz'min (*2*) have reported interferometric radiometer measures at 10.6 cm, which indicate temperatures above 420°K at the poles. Libby (*1*) argues that these results are probably invalid because of the large amount of attenuation caused by the intervening atmosphere. However, the attenuation would act to decrease the observed limb temperature from its true value; this implies that the poles are even warmer than the values suggested by Clark and Kuz'min. Furthermore, these authors found an increase in temperature toward the equatorial limb, where the atmospheric attenuation would be just as large as at the poles.

As a second counterargument to the radio measurements, Libby (*1*) notes that the Soviet space probe Venera 4 recorded a surface temperature of only 550°K, which is considerably lower than the 630° ± 70°K deduced (*2*) for the antisolar point; a temperature of 273°K at the poles might then be within the range of possibility. However, the maximum temperature difference between equator and pole permitted by the interferometric measurements is only 31 percent. This would give a T_{pole} of 380°K if T_{equator} is 500°K. If the full range of uncertainty is allowed, T_{pole} does not fall below 300°K. Furthermore, if the ice caps are to survive over long periods of time, the temperature must be well below freezing over most of the ice-covered region, not just at the poles.

This requirement leads to another contradiction. A large number of measurements at many wavelengths are consistent with the requirement of a mean planetary temperature above 550°K (*3*). If a substantial fraction of Venus is covered by ice caps [Libby (*1*) mentions 30° latitude as a possibility for the extent of the caps], the equatorial region would have to be very hot indeed for such high temperatures to be observed. The rather serious discrepancy between the radius of Venus implied by the Venera 4 results and the radius determined by ground-based radar (*4*) may mean that Venera 4 did not reach the planet's surface. If this is the case, the argument against polar ice caps of any size is virtually irrefutable.

Where then is the water? Any acceptable explanation must account for the absence of large amounts of water on Venus and the present existence of the terrestrial oceans. Mars also appears to possess an atmosphere that can be understood by analogy with the outgassing that has taken place on Earth, again with the exception that water is grossly underabundant (*5*). There are also large differences in the amounts of water present in meteorites. It is very unlikely that the same process for the fractionation of water operated in all of these cases. Nevertheless, it is clear that Earth is really the anomalous planet in the inner solar system in this respect.

It is not yet possible to decide whether water was initially underabundant in the material that ultimately formed Venus or whether the water subsequently escaped from the planet's atmosphere. However, the present existence of large amounts of water on the surface of Venus, in liquid or solid form, does not appear to be consistent with the evidence that we have at our disposal.

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The report by Libby (*1*) at first sight promises a challenging and provocative new idea concerning Venus and has been treated as such by the press (*2*). However, Libby's model inevitably implies either an absurdly large horizontal pressure gradient, or an untenable vertical temperature structure. If we assume that melting at the edges of the ice caps is balanced by snowfall over the caps, then the temperature near the poles must be below freezing through much of the depth of the atmosphere in order to make snowfall possible. The surface temperature and pressure at the equator are 550°K and 20 atm, respectively. The vertical temperature distribution is roughly adiabatic over the equator and, in the simplest case for Libby's model, would be roughly isothermal over the poles. If we assume that the cloud top temperature is more or less uniform as indicated by radiation measurements, a simple calculation shows that the surface pressure at the poles would be about twice the equatorial surface pressure. Such a pressure gradient would imply a pole-to-equator acceleration of the surface winds of nearly 3×10^3 m sec^{-1} day^{-1}. Since the deflecting effect of the Coriolis force on Venus is small, winds of fantastic strength would blow from the pole to the equator. The convergence of air at the equator would lead to huge updrafts over the equator, and by mass conservation huge downdrafts would occur over the poles. The descending air would warm adiabatically and prevent cloud formation and precipitation. This "supersonic Chinook" would quickly melt the ice caps, and when they disappeared the relative calm of the Venus atmosphere would be restored. On the other hand, if the melting were balanced by frost deposits rather than snowfall, then, although the temperature gradient could be adiabatic throughout most of the depth of the polar atmosphere, an extremely intense temperature inversion would still be needed near the surface to bring the air temperature to below freezing at the surface. Such an inversion could not be maintained in the presence of the strong infrared back radiation from the atmosphere and the clouds.

Finally, there is the remote possibility that the polar caps on Venus are elevated plateaus roughly 38 km in height. At these heights an icecap could be maintained which would add another 5 to 10 km to the height. This raises questions regarding the shape of Venus which we are not qualified to discuss, but we suspect that they are serious.

Our comments are intended to illustrate that Libby's speculations, offered to account for the removal of water vapor (for which there is no observational basis and only the most speculative theoretical basis), have rather far-reaching and complex consequences.

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Owen questions my suggestion that there may be ice on Venus because the equatorial surface and at least part of the polar atmosphere is hot. This indeed is a serious objection which we have very carefully considered; on balance in the face of all the evidence—the similarity between the amounts of CO_2 on Venus and on Earth, the Venera 4 findings (*1*) that water and O_2 were present, and the absence of CO, H_2S, and SO_2 in the high atmosphere—we have concluded that there may well be conditions temperate enough to hold the ice.

There are two additional points that were not stated in my report (*2*). The first is that the glacier would be capped by a solid hydrate of CO_2. Takenouchi and Kennedy (*3*) have studied the dissociation pressure of the compound $CO_2 \cdot 5.75\ H_2O$ and have reported on its stability at pressures up to 2000 atm, (melting point 20°C). In the range of 18 to 20 atm, as found on Venus (*1*), the melting point would be 4°C. Experiments in our laboratory (*4*) indicate that the formation of the hydrate from ice is a slow reaction; snow or rain might well deposit as ordinary ice and, depending on the rates, subsequently be partially converted. The second point (*5*) is that the polar areas may be elevated plateaus high enough and cold enough to maintain the ice caps.

The argument that the surface temperature at the poles would be too hot is questionable since the slant path to the polar areas from terrestrial observatories or equatorial planetary probes (Mariner II and Mariner V) would be equivalent to about 250 miles (400 km) of sea-level air on Earth. It seems clear that any precipitation would hide the surface.

Businger and Holton argue against the maintenance of polar ice caps on Venus by a strong inversion layer caused by obscuration of the surface from sunlight by snowfall. They say strong winds would be made to blow from the hot equator.

A calculation of this rate of heat transfer indicates, so far, that a combination of the plateau (*5*) and the inversion layer principles together with partial conversion to the hydrate $CO_2 \cdot 5.75\ H_2O$ may suffice to maintain ice caps.

Only with the greatest reluctance should we relinquish the idea that Earth and Venus, so similar in size and average density, could have similar composition and hence similar volcanic history. The CO_2 on Venus probably came from volcanoes by the reaction of water in the large quantities required with the reduced forms of carbon which occur in meteorites. Therefore, CO_2 production, according to the principle of similarity, should have been accompanied by H_2O, CO, H_2S, and SO_2. However, these gases are of very low abundance (in parts per million or less) (*6*) in the Venus stratosphere and all those (except water) that are permanent gases should be visible if present. From these observations it seems that the Venus atmosphere must be oxidizing. In addition, if we assume Earth-like volcanic activity, the reducing effect of the lava (roughly 5 percent FeO) (*7*) might be expected to produce CO from CO_2. The fact that CO is of very low abundance seems to require a strong source of oxygen, as indicated from Venera 4 data.

The only source of oxygen in accord with these facts (the very dry stratosphere and minimum CO rules out photolysis of water and CO_2) is plant life just as appears to be true on Earth. (*8*). Plant life requires moderate temperatures and water, such as would occur at the margins of ice caps.

My whole argument and conclusions may be quite incorrect but only further experiment can settle the matter. We urgently need a probe landing on the polar areas of Venus.

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