THE TROUBLE WITH VENUS

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Venus is the closest planet. Its surface has never been seen at optical frequencies; nevertheless we now know with at least fair reliability, and in some cases with remarkable accuracy, its surface temperature and pressure, its atmospheric structure, its period of rotation, the obliquity of its rotation axis, the mean surface dielectric constant, its ionospheric structure, and even a little about its surface topography. And yet the clouds of Venus, visible to the naked eye and known to be clouds since the time of Lomonsov, continue to elude our efforts to understand them comprehensively. Not only do we disagree on the chemical composition of the clouds, but it is not even settled whether they are condensation clouds or non-condensable aerosols. And yet there is a very wide variety of relevant data on the clouds. Indeed, the ratio of potentially diagnostic data points to mutually exclusive hypotheses is of the order unity.

This is not the first time that studies of Venus have been beset with troubles, with a simultaneous multiplicity of hypotheses and data. The debate on the nature of the Venus microwave emission bears some interesting parallels, and might conceivably serve as a methodological guide, to studies of the Venus clouds. The natural first explanation of the high microwave brightness temperature of Venus, discovered by Mayer *et al.* (1958) in 1956, was that we are observing thermal emission from a hot surface. But this straightforward hypothesis was greeted by considerable skepticism – some of which, I believe, has psychological rather than scientific roots. If Venus really had a thermometric temperature in excess of 600 K, then a variety of pleasant possibilities – a habitable, ocean-covered Venus, for example – would be removed from the field of reasonable discourse. As new observations of Venus were performed, new varieties of non-thermal explanations for the microwave emission emerged. It is instructive here to consider the evolution of just one of the non-thermal hypotheses, the ionospheric model.

In the ionospheric model, free-free emission in a dense Cytherean ionosphere is invoked to explain the microwave spectrum. The free-free optical depth is given by $\tau \propto \lambda^2 T_e^{-3/2} \int N_e^2 \, dz$, where λ is the wavelength of the emitted radiation, T_e the electron temperature, N_e the mean ionospheric electron density, and z the vertical dimension. The proportionality factors are known. The microwave spectrum, as it seemed to be some years ago, could be explained on this model; setting $\tau = 1$ at $\lambda \simeq 1$ cm, we find that at wavelengths much longer than 1 cm we are observing a constant brightness temperature at the electron temperature, T_e, which is specified at about 600 K. Shortward of 1 cm we look through the now optically thin ionosphere to the lower atmosphere and surface, which to match the microwave spectrum must have low and possibly even congenial temperatures. This was the attractive feature of the model in the original formulation by Jones (1961). But when this model is compared with the

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range of information known about Venus before the space vehicle successes of mid-October 1967, it runs into an impressive variety of independent embarrassments. First, the value of $\int N^2{}_e \, dz$ is specified by the requirement for a fit to the microwave spectrum. The resulting values of the electron density are 10^9 or 10^{10} electrons cm^{-3}, some three or four orders of magnitude greater than the peak ionospheric electron density on the Earth. Even under the most generous assumptions, it is difficult to justify such high electron densities on Venus. Secondly, an optical depth of unity at 1 cm wavelength implies an optical depth at 68 cm wavelength, say, of $(68)^2 = 4624$. But, in fact, radar reflectivities of 10 or 15% were known at 68 cm wavelength. A third and weaker piece of conflicting evidence is the fact that the interferometric radius of Venus is less than the optical radius of Venus, implying that the emitting region lay below the clouds – consistent with the hot surface model – rather than above the clouds, as is evidently required by an ionospheric model.

Finally, the requirement of optical depth unity near 1 cm implies that Venus should exhibit limb brightening at wavelengths near 1 cm – because, as we scan from the center of the disk towards the limb, we are looking through longer paths of the emitting layer. On the other hand, if we were to believe the hot surface model, the opacity at 1 cm must be attributed to the atmosphere or clouds – this was realized more than a decade ago – and Venus at 1 cm should exhibit limb darkening and not limb brightening. Interferometric studies of Venus at such short wavelengths were impossible in the 1960's and remain impossible today. The question of limb darkening or limb brightening at 1 cm wavelength could, therefore, be most expeditiously settled by flying a small microwave radiometer to the vicinity of Venus and crudely scanning across the disk – an objective of the Mariner II mission to Venus. This is, incidentally, an excellent example of a critical experiment, performed by space vehicle, that could not be performed from the surface of the Earth. Despite time-constant problems and calibration difficulties, particularly on the 13.5 mm channel of the Mariner II radiometer, the 19 mm channel showed distinct limb darkening consistent with the hot surface model and inconsistent with the ionospheric model (Barath *et al.*, 1964).

With such an array of data opposed to the ionospheric model, it would seem that the model would have had no adherents by the mid-1960's. This, however, was not the case. It is always possible to make *ad hoc* revisions of a simple theory, in order to keep up with the accretion of embarrassing data. Thus, it was proposed that ion-electron recombination in the Venus ionosphere might be sufficiently rapid for there to be a hole in the center of the night hemisphere, large enough for the first radar Fresnel zone to penetrate the ionosphere at inferior conjunction and be reflected by the surface but small enough not to compromise the passive microwave emission coming primarily from the ionosphere. The limb darkening difficulty could be explained away by postulating a sufficiently ingenious array of ionized layers, strategically placed. And, in one attempt to come to grips with the high electron density implied for free-free emission, it was suggested that the bulk of the microwave emission comes, not from the interaction of charged particle with charged particle, but from the interaction of charged particle with the instantaneous Coulomb field of molecules in the neutral atmosphere. This idea requires very frequent collisions to explain the observed micro-

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wave intensity. The required density of neutral atmosphere would place the Venus ionosphere well below the visible cloud tops, roughly at the 1 bar pressure level. But at such depths adequate ionization either from solar electro-magnetic or solar particulate radiation is not to be expected. Accordingly, it was seriously proposed in one paper that the required high ionization rate deep in the clouds of Venus may be due either to a significantly greater primary cosmic ray flux at Venus than at Earth, or to many orders of magnitude more radioactive materials in the atmosphere of Venus than of Earth – evidently the result of a Cytherean nuclear war. These examples illustrate an understandable and very human tendency towards the selective rejection of disquieting data, and the lengths to which a sufficiently desperate theoretician may be driven. The failure of the ionospheric model may not be merely of academic interest: the epic-making Soviet entry vehicle, Venera 4, appears to have been crushed by the weight of the overlying atmosphere at the 550 K, 20 atmosphere level. Might this be due to a too confident reliance on the ionospheric model – which implied, because of the low surface temperatures, pressures of at most a few atmospheres?

Before the Venera 4, and Mariner V successes, it was possible to construct a truth table which compared the range of observations with the range of models. The observables in question were the microwave spectrum, the phase effect (about which, more in a moment), interferometric observations, the Mariner II limb darkening observations, the radar spectrum and the radar diameter. Tested against these observations were models of synchrotron or cyclotron emission, the free-free emission model just discussed, a glow discharge model, a droplet electrical discharge model, and the hot surface model. Only the hot surface model survived analysis by such a truth table (Sagan, 1967, 1969).

Another interesting implication of the debate on the Venus microwave emission is the possible existence of false positives. The reported variation of the microwave brightness temperature with phase angle at 3.15 and 10 cm wavelength had precisely the form anticipated from the solution of the one-dimensional equation of heat conduction for an impressed sinusoidal thermal wave. The time-independent components of the brightness temperature at the two wavelengths were the same, as they should be; the amplitude of the time-dependent term declined with depth and the phase lagged with depth, again as the theory of heat conduction predicts. This seemed to be so clearly what is expected for a hot surface heated by sunlight that a detailed analysis of the data appeared warranted (Pollack and Sagan, 1965); the analysis gave values for the sense of rotation of Venus, the obliquity of its rotation axis, the dielectric constant, and the ratio of electrical to thermal skin depths of the surface material which were entirely consistent with other information – primarily radar data.

Nevertheless, and in spite of great care taken by the observers to insure the reality of the reported phase effect, the observations appear to be in error. Observations at wavelengths of 4.15 cm and 2 cm, respectively (Dickel *et al.*, 1968; Morrison, 1969), and a more recent set of 3 cm observations at the Naval Research Laboratory (Mayer, 1969) fail to show any statistically significant phase effect whatever. Indeed, because of the large heat capacity and infrared opacity of the massive atmosphere known to

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exist on Venus, a detectable microwave phase effect is not to be expected – a point which also emerges in a novel context in Golitsyn's (1970) similarity theory of the Venus atmospheric circulation. And the possibility that both the early observations, which show a phase effect, and the more recent observations, which do not, are correct – entailing very special emissivity distributions over the disk, or the outgassing of many tens of atmospheres in less than a decade, or an extremely prolate and nutating planet – seem too desperate even for Venus. We seem to be faced with the possibility that Nature and radioastronomical techniques have contrived a noise spectrum which simulates the solution of the one-dimensional equation of heat conduction.

It seems to me that a related procedure, also using a truth table, and bearing in mind the possibility of false positives, might be very useful in studies of the vexing questions of the nature and composition of the Venus clouds. Even though the relevant observables about Venus are not in as good an observational shape as could be desired, they can be used to test the various models. Among the observations and consistency checks which seem relevant are the following: (1) the absorption in the blue and ultraviolet, which gives Venus a naked eye color which is approximately a pale lemon yellow; (2) the very high visible albedo of Venus; (3) the near infrared spectrum of Venus, which is approximately flat between 0.7 μ and about 2 μ (although there is some dispute about the reality of features reported at 1.5 and 2 μ), and a precipitous decline longward of 2 μ to an extremely low albedo which appears to remain constant between 3 and 4 μ; (4) the microwave spectrum between a few millimeters and some meters, which now appears to have a peak in the vicinity of 6 cm; (5) the radar spectrum; (6) direct chemical investigations by Veneras 4, 5, and 6; (7) possible attenuation layers in the Venus atmosphere which may have been observed by the Mariner V S-band occultation experiment; (8) consistency of proposed compositions with the pressures and temperatures known near the clouds; (9) the dependence of the polarization of scattered light on phase angle and on wavelength; (10) the dependence of the geometric albedo on phase angle and on wavelength, as in the halo effect; (11) the density of scatterers in the clouds, as determined from near infrared spectroscopy; and (12) the question of support of aerosol particles, in the case of non-condensable clouds. There are also questions of (13) the geochemical plausibility and (14) the cosmic abundance of proposed cloud constituents.

To be run against these observables in the truth table are at least the following proposed cloud constituents: (a) 'dust' – that is, various geochemically common silicates and oxides; (b) hydrocarbons; (c) carbon suboxide and its polymers; (d) ammonium chloride; (e) various mercurous halides; (f) ferrous chloride dihydrate; (g) polywater; (h) water ice. All these materials have been seriously proposed as principal constituents of the Venus clouds. While, for the truth table analysis of the microwave emission, it did not turn out that mixed hypotheses were necessary – that a significant contribution to the microwave emission came from two conceptually distinct sources – it is nevertheless possible that 'the' clouds are not composed entirely of one material, or that there is more than one cloud layer, different layers contributing in different proportions to the parameters (1) through (14) above. I think the time is rapidly approaching when a systematic truth table analysis, involving (1)

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through (14) and (a) through (h), can be drawn up. I do not propose to make such a truth table here, but I cannot resist the temptation to discuss how ice clouds would fare in such an analysis, and to make a few critical comments on some of the other proposed cloud constituents:

In order to support ice crystal clouds at approximately the 230 K temperature level (corresponding to a few tenths of a bar pressure), it is easy to show that the present Venus atmosphere below the clouds and far from saturation must consist of a few tenths of a percent water vapor mixing ratio by volume. This is just the amount announced by independent observations aboard Veneras 4, 5, and 6. While there is some cause for skepticism, particularly about the Venera 4 oxygen measurements, this does not seem to be the case for the water vapor measurements, as discussions at conferences in Marfa, Wood's Hole, and elsewhere clearly indicate. I think we must take seriously the Venera water vapor results. Next, it has long been known that a few tenths of a percent water vapor mixing ratio is the sort of value needed, along with CO_2, to explain the high surface temperature of Venus via the greenhouse effect (Sagan, 1960); and this conclusion has recently been confirmed in detail by Pollack (1969) and by Ohring (1969). As we have heard at this meeting (Pollack and Morrison, 1970), the microwave spectrum of Venus in the vicinity of 13.5 mm is definitely consistent with, although not uniquely indicative of, a water vapor mixing ratio of a few tenths of a percent. In addition, the radar observations require an additional opacity source, consistent with a few tenths of a percent water vapor (Kroupenio, 1970). Note that the Venera measurements, the greenhouse model calculations, the microwave resonance line and the radar spectra are the only means now available for probing the water vapor content of the lower atmosphere of Venus. They all give results consistent with ice clouds on Venus.

The infrared spectrum of the Venus clouds is very close to that of ice crystals with particle sizes in the few micron range; in particular, the deep and flat absorption longward of $3\,\mu$ strongly indicates the presence of condensed rather than bound water (Pollack and Sagan, 1968). Plummer (1970b) argues that the $2\,\mu$ ice band is present also, implying particle dimensions of several microns. The high visual albedo is just in the range expected for multiple scattering in ice clouds with particle dimensions of a few microns, and the cloud density once advertised as much too diffuse for consistency with terrestrial ice clouds now emerges – after allowance for anisotropic multiple scattering is made – as precisely in the range of terrestrial cirrus clouds (Potter, 1969a; Hansen, 1969). A Venus halo effect, characteristic of hexagonal ice crystals, has been sought for by O'Leary (1967) near phase angle $180° - 22° = 158°$. O'Leary found a marginal positive result from his earlier measurements, and a somewhat more definite identification in his more recent efforts (O'Leary, 1970). He finds that a larger halo effect would have been observed if $> 5\%$ of the multiply scattering clouds are composed of pure hexagonal ice crystals of radii $>$ a few microns, where diffraction is small. But since the infrared spectra imply a particle size distribution function peaked at a few microns, and since the clouds are surely not without contaminants (see below), O'Leary's observations seem to imply ice crystals as a major cloud constituent. The increased reflectivity at a given phase angle depends not only on the

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real part of the refractive index, but also on the geometry of the scattering crystals. Veverka (1971) has searched unsuccessfully for a polarimetric halo effect at 158°; but his sensitivity was such that his negative findings are not in contradiction to O'Leary's results. There is no inconsistency with water ice clouds in the radar spectrum or in the occultation measurements.

The ultraviolet albedo of water clouds is much higher than that of Venus; the real part of the refractive index as extracted from polarization measurements by Coffeen (1968) is > 1.43 compared to about 1.3 for pure ice. However, both these observations can be very trivially made consistent with ice clouds if we include an admixture of dust particles, particularly those containing iron which gives a strong ultraviolet absorption and a large refractive index. Indeed, the rings of Saturn, which now appear clearly as largely water ice, also exhibit absorption in the blue and ultraviolet, probably for similar reasons. The photometric properties of the Venus clouds in the visible are consistent with ice clouds with particle diameters of a few microns (see, e.g., Arking and Potter, 1968; Potter, 1969b).

One of the major arguments against water ice as a principal constituent of the Venus clouds has for many years been the apparent inconsistency between the spectroscopic abundances and the equilibrium vapor pressures at the presumed cloud temperatures (Sagan and Kellogg, 1963; Chamberlain, 1965; many subsequent papers). As the vapor pressure goes exponentially as the negative reciprocal temperature, a variation of a few tens of degrees in estimates of rotational temperature implies many orders of magnitude variation in the derived water vapor abundance. Considering the apparent time-variability (Schorn *et al.*, 1969) in the near-infrared spectroscopic water vapor abundances (possibly connected with the four day retrograde rotation in the clouds?); the range of reported cloud temperatures (210–250 K); possible departures from saturation above the clouds; and the effects of inhomogeneity and anisotropy in the clouds (see, e.g., Sagan and Regas, 1970), I am not convinced that the infrared spectroscopic measurements provide a crushing argument against the case for ice clouds on Venus – although they represent certainly the strongest adverse argument. At one time it appeared that ice clouds were inconsistent – at least at thermodynamic equilibrium – with the quantities of HCl and HF determined from the Connes interferometric spectra. But more recent calculations, performed with the water vapor abundance as an unknown, shows this apparent inconsistency to be almost removed (Lewis, 1969a).

All of the other proposed principal cloud constituents seem to run into one or another difficulty: 'dust' introduces problems about the ability of the slow Venus circulation to raise and maintain dense aerosols, as well as difficulties with the absence of huge quantities of SiF_4 (Lewis, 1969b) and with the infrared spectrum; NH_4Cl runs into problems with the amount of gaseous ammonia needed in equilibrium with it; there are doubts on the very reality of polywater, and about the interpretation of occultation attenuation data in terms of clouds rather than scintillation eddies in the Venus atmosphere (Fjeldbo, 1969); carbon suboxide and hydrocarbons do not appear to match the Venus infrared spectrum (Plummer, 1970a, 1969), and the latter are particularly unlikely because of the absence of evidence for simple gaseous hydro-

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carbons in equilibrium with putative hydrocarbon clouds (Sagan, 1961). As for $FeCl_2 \cdot 2H_2O$, it is unstable in the presence of the water abundances quoted by the Venera 4, 5, and 6 experimenters; and, while it shows an absorption at 3 μ, the feature has shallow wings and does not have the saturation character of the infrared observations. The 3 μ absorption in $FeCl_2 \cdot 2H_2O$ is in fact due to water, but in the bound state. A stronger absorption can be obtained with more bound water per $FeCl_2$ moiety, but the vapor pressure data seem to be inconsistent with the tetra-hydrate or higher hydrates (Kuiper, 1970). John Lewis (private communication, 1970) points out that $FeCl_2 \cdot 2H_2O$ is so involatile it should condense out at > 500 K, and at this symposium both Kuiper and Sill have mentioned attendant serious transport problems, and the necessity to postulate strong departures from equilibrium.

Perhaps none of these objections will be considered individually decisive. The question of the composition of the Venus clouds is by no means solved, at least to the satisfaction of all investigators in the field at the present time. But I will be surprised if we are more than a few years from such a solution.

There are a range of other troubles with Venus. The structure of the atmosphere seems reasonably well-determined (Figure 1), although the variation of this structure with position on the disk and with time of day needs to be studied further. Another question is whether the clouds of Venus ever exhibit breaks. The impression of almost

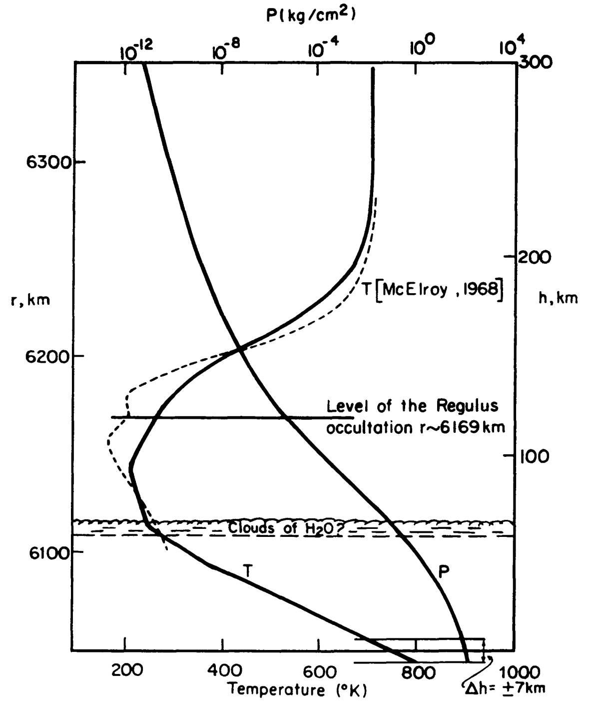

Fig. 1. Structure of the Venus atmosphere as determined from Veneras 5 and 6. This diagram is redrawn from one in the paper by Avduevsky *et al.*, 1970 (and with the addition of the question mark in the clouds).

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all observers is that the Venus cloud deck is uniform and without breaks. But on rare occasion there have been reports of breaks in the clouds. One such event is recorded in the drawing by J. H. Focas, reproduced in Figure 2. We can compare this unusual representation of Venus with the usual representation of the earth in Figure 3 at

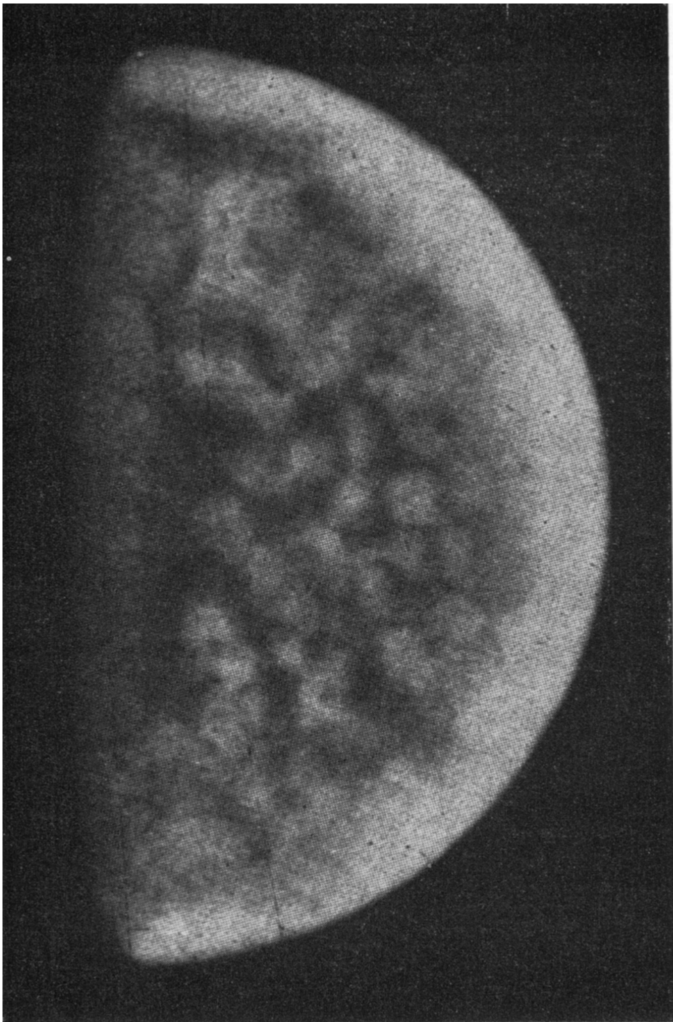

Fig. 2. An unusual drawing of Venus by J. H. Focas showing apparent resolution of the clouds into individual elements [taken from *Atlas des Planètes* (ed. by V. de Callataÿ and A. Dollfus), Gauthier-Villars, Paris, 1968].

approximately the same phase angle. The search for such breaks requires high resolution and is a natural experiment for a Venus orbiter. (Such vehicles will also be of very great importance in mapping temperatures and water vapor abundances over the disk of the planet.) The radar altimeters on the Venera 5 and 6 spacecraft give a variation

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Fig. 3. Apollo photograph of the Earth taken at very roughly the same phase angle as the drawing of Venus in Figure 2. The Earth shows about 50% cloud cover.

in altitude of the respective landing sites of many kilometers. This appears to be inconsistent with the time delay radar measurements of topography performed at Lincoln Laboratory (Smith *et al.*, 1970), but the lateral resolution of the ground-based radar is some hundreds of kilometers; perhaps at a much smaller lateral resolution scale the topography is rougher. Why Venus should be rotating in a retrograde direction, why it should be locked or almost locked in rotation at moments to inferior conjunction with the earth (see, e.g., Gold and Soter, 1969), and why the clouds of Venus show a four day retrograde rotation are clearly important problems which are

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far from solved at the present moment. The radar topography of Venus suggests mountain ranges and large circular basins (impact craters?), but definite knowledge of the geomorphology of Venus lies in the future. A similar remark applies to meteorological questions of the circulation of the Venus atmosphere, both in the stratosphere (see, e.g., Gierasch, 1970), and in the deep atmosphere. And the explanation of the high surface temperature of Venus is certainly one of the major intellectual problems about the planet. There is a misimpression occasionally encountered that the large optical depths required for ice clouds to explain the high visible and near infrared albedos imply that very little sunlight penetrates through the clouds to the lower atmosphere and surface. This is incorrect. Clouds of water ice need not produce a 'dirty' greenhouse, and 10 to 20% of the incident sunlight would emerge out of the bottom of reasonable ice clouds (Sagan and Pollack, 1967; Pollack, 1969). Although the case for the greenhouse model is, I believe, better today than it ever was, there is still no unanimity on the subject.

Even if the Venus atmosphere is composed of as much as a few tenths of a percent of water vapor by volume, there is a large discrepancy between the water abundance in the atmosphere of Venus and that in the atmosphere and hydrosphere of the earth – a discrepancy of perhaps a factor of a thousand. Here again the variety of explanations put forth seriously, is, at the very least, sobering. Venus may have started out with much less water than the earth because it was closer to the sun – although this explanation tends to put the problem out of reach, depending on initial and inaccessible conditions. Serpentinization of olivine may be responsible, although why this should be more effective on hot Venus than on cool earth is far from clear (Sagan, 1960); nevertheless, Rubey (1969) states that this may be a promising possibility. Perhaps all the water is locked up as polywater (Donahoe, 1970), although again why this should occur more readily on Venus than on Earth is far from clear – even if we admit the reality of anomalous water. Finally, perhaps the two planets started out with comparable complements of water, but photodissociation of water, selective escape of hydrogen, and preferential oxidation of the crust of Venus by huge quantities of oxygen occurred (see, e.g., Sagan, 1968; Eck *et al.*, 1967). Calculations suggest that this is barely possible, but it requires very special circumstances and is not an idea marked by a striking economy of hypothesis.

The microwave, Venera, and Mariner observations and the Golitsyn (1970) similarity theory all seem to imply that there is nowhere on the Venus surface where liquid water could exist – even with a surface pressure of 100 atm. Accordingly life, particularly life based on familiar chemistries, seems implausible on the Venus surface (cf. Sagan, 1970). This leaves the clouds. Especially if the clouds are composed of condensed water – but even if they are not – life in the clouds is not by any means out of the question. There is water vapor, there is carbon dioxide, there is sunlight, and very likely there are small quantities of minerals stirred up from the surface. These are all the prerequisites necessary for photoautotrophs in the clouds. In addition the conditions are approximately S.T.P. The only serious problem that immediately comes to mind is the possibility that downdrafts will carry our hypothetical organisms down to the hot, deeper atmosphere and fry them faster than they reproduce. To circumvent

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this difficulty, and to show that organisms might exist in the Venus clouds based purely on terrestrial biochemical principles, Harold Morowitz and I (1967) devised a hypothetical Venus organism in the form of an isopycnic balloon, which filled itself with photosynthetic hydrogen and maintained a constant pressure level to avoid downdrafts. We calculated that, if the organism had a wall thickness comparable to the unit membrane thickness of terrestrial organisms, its minimum diameter would be a few centimeters. This heuristic argument had at least one salutary consequence: The *Saturday Evening Post* ran a cartoon showing a ping pong player (dressed in Florida sports shirt and Bermuda shorts) about to serve, and interrupted by the cry from his ping pong ball, "Stop! I am a friendly visitor from another planet!"

While it is not out of the question that life exists in the Venus clouds, it seems quite unlikely to have arisen there. If we wish to take seriously a possible exobiological interest in Venus, we must postulate some earlier epoch (perhaps before outgassing produced a large atmospheric infrared opacity, a strong greenhouse effect, and high surface temperatures) when the surface conditions were much more clement. Thus the runaway greenhouse scenario (Sagan, 1960) seems connected with the question of life on Venus.

The probability that the clouds of Venus are such a pleasant environment – the most earth-like extraterrestrial environment in the solar system, so far as we know – opens up the perhaps amusing prospect of astronauts floating in somewhat larger balloons, ballasted and valved for the pressures of the lower Venus clouds, and clad in shirtsleeves and 19th Century oxygen masks. We can imagine them peering wistfully down at the inaccessible surface of Venus below – wistfully, because Rayleigh scattering in an atmosphere with 100 bar surface pressure will prevent them from seeing any images of surface features, even if there are breaks in the clouds (although, in the vicinity of 1 μ, there might just conceivably be an imaging window between the extinction due to Rayleigh scattering at shorter wavelengths and the extinction due to molecular absorption at longer wavelengths).

Rather than such a manned venture, most of us would much prefer to see a series of small orbiters and entry probes (cf. Hunten and Goody, 1969) and perhaps unmanned buoyant stations to more thoroughly characterize our still enigmatic nearest planetary neighbor. Until then, I suspect we shall continue to have some trouble with Venus. But perhaps, in paraphrase of *Julius Caesar*, Act I, Scene 2, "the trouble lies not in our stars but in ourselves".

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