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# A COMPARISON OF TWO GREENHOUSE MODELS FOR THE CYTHEREAN ATMOSPHERE

by

Robert B. Owen

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## ABSTRACT

From a survey of present literature a comparison of two Greenhouse atmospheric models of Venus is presented. Recent measurements (Spinrad) [ 1] indicate that the amount of water vapor existing in the atmosphere is sufficient to maintain the original Greenhouse model (Sagan) [ 2]. The new model advocated by Sagan, more consistent with recent observations, indicates more extreme surface conditions than have been previously suspected. With surface temperatures as high as 750° K and surface pressures of over 30 atmospheres, a surface landing presents complex engineering problems.

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## SUMMARY

From a survey of present literature a comparison of two Greenhouse atmospheric models of Venus is presented. Recent measurements (Spinrad) [1] indicate that the amount of water vapor existing in the atmosphere is insufficient to maintain the original Greenhouse model (Sagan) [2]. The new model advocated by Sagan, more consistent with recent observations, indicates more extreme surface conditions than have been previously suspected. With surface temperatures as high as 750$^{\circ}$ K and surface pressures of over 30 atmospheres, a surface landing presents complex engineering problems.

## SECTION I. INTRODUCTION

The currently accepted model for the Cytherean atmosphere is one of the Greenhouse variety. By Greenhouse effect we mean that the incoming solar radiation striking the surface is re-radiated in the infrared. This infrared radiation cannot escape from the lower atmosphere, and thus is reflected back to the surface. The continued reflection of this infrared radiation heats the surface to an extremely high temperature. Recent observations have necessitated certain modifications in the "standard" Greenhouse model. These observations indicate that surface conditions are even more extreme than originally expected.

## SECTION 11. DESCRIPTION OF THE ORIGINAL GREENHOUSE MODEL

The original Greenhouse model, as presented by Sagan [3], is referred to in this report as Model "A" and can be described as follows: Some visible solar radiation penetrates the cloud cover and strikes the surface, which upon being heated radiates in the infrared. This infrared radiation is trapped in the lower atmosphere because of molecular absorption and light scattering in the cloud cover. Thus, the 3 to 21 cm emissions, which indicate black-body temperatures of approximately 600° K, arise from the surface. In this model the 8000 Å $CO_2$ band shows temperatures of 285° K, and the 8 mm band shows temperatures of 350° K, with both arising from somewhere in the atmosphere. The required opacity for this model cannot be due to $CO_2$ alone; however, if 10 gm/cm$^2$ of $H_2O$ vapor are assumed, infrared opague conditions are achieved. With a constant $H_2O$ mixing rate and an adiabatic lapse rate, the water vapor will saturate the atmosphere at 36 km. In this model the far infrared radiation will arise from about 35 km, and since this radiation indicates a temperature of 234° K at that level, an ice-crystal layer should be formed. Near infrared spectrophotometry by Sinton [4] shows absorption features attributed to ice at the same temperature level from which the far infrared thermocouple radiation arises. Above these cirrus clouds, $CO_2$ ionization as well as $N_2$ ionization will occur, if any nitrogen exists.

Until fairly recently, there was much to recommend this model. In addition to Sinton's spectrophotometry, Strong's balloon observations also indicated the required amount of water vapor existed above the cloud layer. It has been conclusively demonstrated that a fairly dense water cloud layer with ice-crystals above it can explain the microwave spectrum and phase effect [3]. Sinton [4] stated that an ice-crystal cloud below the visible cloud layer at about 35 km altitude would handle the Greenhouse effect nicely. The ice-crystal cloud would explain emission at 10 μ [5], and it would also account for the observed albedo of Venus [3]. The theory of radiation, if one assumes a surface temperature of 600° K, implies an ice-crystal layer at 30-40 km, according to Sagan [3]. The small temperature differences observed between the dark and light sides at some wave lengths are explainable by cloud condensing [3]. The existence of the high surface temperature incorporated in this model has been definitely demonstrated by Mariner II measurements [6]. The microwave radiometers indicated a distinct limb-darkening, which eliminates cool surface models.

On the basis of assumed radiative transfer [3], i.e., that the optical atmosphere would scatter radiation isotropically, a composite rotational temperature of $285 \pm 9^\circ$ K has been derived from the $CO_2$ bands in the 8000 Å region. By considering the effects of pressure broadening of the spectral lines in an adiabatic atmosphere, the temperature of the bottom of the indicated bands has been found to be about $320^\circ$ K. These rotational temperatures must come from deeper levels than the thermocouple temperatures, probably from below the visible cloud layer. This is evidence for the transparency of the visible cloud layer in the near infrared.

The observed 8 mm phase effect is the result of a cloud layer which appears opaque at mm wave lengths and transparent at cm wave lengths and is condensable or sublimeable. According to Sagan, on the light side the cloud vaporization would increase; thus, the attenuation of emission from the surface would decline [3].

Sagan used the following equation [7] for radiation balance at the top of the atmosphere:

$$\sigma Te^4 = \sigma Ta^4 + (1 - \alpha)\, \sigma Ts^4$$

where: $\sigma$ = Stefan-Boltzmann constant

Te = Effective temperature of the incoming solar radiation

Ta = Effective radiative temperature of the atmosphere

Ts = Surface temperature

and

$(1 - \alpha)$ = Transmissivity of the atmosphere for infrared.

The following values were assumed:

Ts = $600^\circ$ K

Te = $254^\circ$ K

and

$$Ta = 234^\circ K$$

The results [3] indicate that the Greenhouse effect would raise the temperature of the 8000 Å band to 280° K. This is excellent agreement with the rotational temperature for these bands, which is 285 ± 9° K, and provides additional evidence that these bands originate from beneath the cloud layer, since otherwise the Greenhouse effect would raise the temperature at the visible cloud layer to 280° K.

The observed abundance of $CO_2$ on Venus [8] indicates that the Urey equilibrium does not occur. This equilibrium involves reactions between surface silicates and $CO_2$ as follows:

$$MgSiO_3 + CO_2 \overset{H_2O}{\rightleftharpoons} MgCO_3 + SiO_2, \text{ and}$$

$$CaSiO_3 + CO_2 \overset{H_2O}{\rightleftharpoons} CaCO_3 + SiO_2$$

The occurrence of these reactions would result in a much smaller $CO_2$ abundance. The Urey equilibrium fails to occur on Venus, because the required liquid water catalyst probably does not exist under the conditions indicated by the Greenhouse model.

Ohring [9] made some new radiation balance calculations in which the cloud cover was considered more strongly. He assumed that the cloud top is at a high altitude and radiates as a black-body at a temperature of 235° K, and that there is no absorption above the cloud top. His results indicate that the clouds enhance the Greenhouse effect greatly, and it is implied that the requirements for large amounts of infrared absorbing gases are diminished as the amount of cloudiness increases.

## SECTION III. OBJECTIONS TO THE ORIGINAL GREENHOUSE MODEL

There were several objections raised as to the validity of the Greenhouse effect. Some difficulties in convection were noted. Mintz [10] doubted that the short wave absorption could remain small enough to allow the sunlight penetrating the clouds to suffice for the maintenance of both the high surface temperature and the convection necessary to keep the cloud particles suspended. Assuming the Greenhouse effect existed, the spherical form of the planet would give rise to a large horizontal heating gradient from the equator to the poles. On a slowly rotating planet, such a gradient would result in a strong meridional circulation, and the Greenhouse effect would be opposed by the resulting vertical heat transport.

The main objection raised to the described Greenhouse model was the apparent lack of the required water vapor. The observed pressures and temperatures from observations of the 7820 Å $CO_2$ band intimate that it should penetrate deeply into the Cytherean atmosphere, but Spinrad's [1] observations at this wave length found no indications of water. Without significant water vapor, the $CO_2$ alone is not enough to account for the necessary opacity, and it is difficult to see the formation of the required cirrus clouds.

## SECTION IV. DESCRIPTION OF THE PRESENT GREENHOUSE MODEL

There appeared to be no way to account for the large temperature gradient measured between the surface and the cloud tops. However, recent observations made with improved instruments indicate that there is a phase variation; and interpretation of this fact produced the following Greenhouse model, "B," which dictates surface conditions even more extreme than were formerly thought to exist [2]. This phase variation necessitates a subadiabatic dark side lapse rate. A surface temperature difference between the dark and light sides of at least $70^{\circ}$ K is indicated by all observers; and by incorporating this new information into model "A," Sagan [2] derives the following conclusions:

It is estimated that the pressure at cloud level on the sunlit side is $\geq$ pressure at the cloud level on the dark side and that the $CO_2$ mixing rate $\alpha \sim 0.05 - 0.15$. The temperature and pressure at the occultation level is $203^{\circ}$ K and $2.6 \times 10^{-3}$ mb. These values are derived from the occultation of Regulus, which occurred at $55 \pm 8$ km above the visible cloud layer. The temperature at cloud level is $234^{\circ}$ K, and the pressures there are 90 mb on the dark side, and 0.6 atm or approximately 670 mb on the light side. It is assumed that no significant water vapor exists. With a lapse rate between 1/2 and 1 times the dry adiabatic lapse rate and a surface temperature of 740° K, the surface pressure is at least 30 atm. Since nearly synchronous rectrograde rotation is indicated by observations, a mean wind velocity of 0.15-0.10 m/s is required to carry the necessary energy from the light side to the dark side. With the resulting Rayleigh scattering, the only wave length that would reach the surface is near infrared, which could do so only in breaks in the somewhat turbulent cloud cover. The high temperatures and pressures would provide the necessary cloud opacity by thermal excitement of low-lying rotational states, pressure broadening of line contours, and pressure induced dipole transitions and volatilization of surface material. Various measurements at different wave lengths from visible to far infrared infer that the main reflection surface is the visible cloud cover. Based on the radar values for emissivity, the bright side surface temperature is 750° K, and the dark side surface temperature is 640° K. The dark side lapse rate is estimated to be 1/1.5 ± 0.4 times the dry adiabatic lapse rate, and the cloud altitude on that side should be 80 ± 20 km; while on the bright side, if there is really a significant difference in the cloud top pressures, the visible cloud top altitude is probably somewhat higher.

## SECTION V. OBSERVATIONS FAVORABLE TO PRESENT GREENHOUSE MODEL

This model removes the old objections to the Greenhouse model, and it is backed up by many recent observations [2]. Analysis of the 7820 Å band of old Mt. Wilson spectra revealed varying rotational temperatures and line contour pressures. This indication of day-to-day variation in the cloud cover implies higher surface temperatures and pressures than had been previously expected. The conclusion [2] of a single reflecting cloud is based on the fact that observations using various wave lengths indicate about the same temperature, and any variations are probably due to fluctuations in the cloud cover. By utilizing the occultation pressure of Regulus [11], the main reflecting layer may be inferred [2] to be the visible cloud cover.

There are several lines of argument to back up the conclusion of very high surface pressures. If one assumes a dry adiabatic lapse rate [2], coupled with a surface temperature of 740° K, the resulting surface pressure is 4.5 atm; but since the lapse rate is subadiabatic, the surface pressure is far greater than 4.5 atm. The surface temperature is based on black-body microwave readings of about 660° K and radar measurements which result in an emissivity of about 0.9, thus deriving a surface temperature of about 740° K. Also, if the indicated microwave attenuation at greater than 3 cm is actually significant, and if the bright cloud top pressure is really higher than the dark side cloud top pressure, [2], the attenuation will raise the surface temperature and the pressure differences will raise the surface pressure. Calculations [2] made with the various possible parameter values result in surface pressures as high as several hundred atmospheres.

An independent method of deriving high surface pressure is based on the breakdown of the Urey equilibrium [2]. By assuming that Earth and Venus had the same initial amount of $CO_2$, a partial pressure for $CO_2$ of 16 atm may be obtained, and if the atmosphere is assumed to be 20% $CO_2$ and 80% $N_2$, the resulting surface pressure is 55 atm. If the mixing ratio is assumed to be 0.05, as indicated by Regulus [11] occultation, a surface pressure of 210 atm is obtained.

A third method of deriving high surface pressures is by consideration of the reduction of the 7820 Å band [2]. By assuming that the cloud deck has a sharp upper boundary and that the distribution of scatterers does not follow the distribution of absorbers [2], consistent values for temperature may be obtained from the distribution of the intensity of the rotational components of the band. The pressure at the bottom of the band is found to be about 10 atm and the temperature is 440° K. Upon assuming a surface temperature of 670° K, this information indicates surface pressures of 27 and 42 atm; while if a surface temperature of 800° K is assumed, the resulting surface pressures are 55 and 82 atm. If the lower atmospheric lapse rate is assumed to be subadiabatic, surface pressures lower than 30 atm are impossible to derive.

The Rayleigh scattering resulting from this model should yellow the sky, thus explaining the color of Venus. This color should be a function of phase [2].

Both visual and photographical studies and near infrared spectroscopy indicate a variable visible cloud cover [2]. Temperature variations indicate that moments of clearing do occur, in spite of measurements at 8-13 $\mu$ which indicate a 99% cloud cover. With the high surface pressures, clouds as high as 40-50 km may be effected by surface features. These lower clouds may not be seen in the visual, because of Rayleigh scattering, but they could be photographed in ultraviolet. Near infrared one could observe these clouds and the lower surface as well through a break in the cloud cover.

Ohring [9] made some calculations relating the magnitude of the Greenhouse effect to the cloudiness and opacity of the atmosphere by assuming that Venus has a grey atmosphere and an extensive cloud cover that is opaque to infrared, but transparent to solar radiation that is not reflected by the cloud top. He also assumed an adiabatic lapse rate. From this he concludes that a $600^{\circ}$ K surface temperature may be maintained by the Greenhouse model with utilization of the opaque clouds and the $CO_2$ concentration and that there is no need for any additional absorption molecules, although such a molecule would enhance the Greenhouse effect and cut down the requirements for cloudiness and/or $CO_2$.

Several doubts still exist about this model. All methods of establishing it suffer from lack of observational material [2]. Harteck [12] has indicated that chemical reactions which should occur in the Cytherean atmosphere may be, in part, responsible for some of the microwave emissions. Cloud composition and thickness is uncertain [9]. The amount of radiation absorbed by the clouds has not been resolved, and with surface pressures of perhaps 50 atm, it is not known how much radiation ever reaches the ground. However, at the present time this model appears to be the most valid. Some parameters established by this model appear in Table I.

## SECTION VI. CONCLUSIONS ON SURFACE CONDITIONS

Thus, the surface of Venus appears to be a forbidding place, with surface temperatures comparable to a red-hot oven and pressures that exist on Earth only many meters under the Ocean [2]. Since the melting points of aluminum, lead, tin, magnesium, zinc, and bismuth may be reached; pools of molten surface material may cover much of the bright side [2]. The high pressures may produce clouds of exotic materials from substances that would ordinarily be gases at such temperatures. The temperature of the dark pole has been established by Drake to be 540° K, and with the high surface pressures, several possible constituents of the lower atmosphere may condense out. Possible polar seas may contain liquid benzene, liquid acetic acid, liquid butyric acid, liquid phenol, and if the pressure exceeds 60 atm, perhaps a bit of liquid water. If ammonium chloride is present, it will condense out over most of the dark hemisphere; and the reaction of $N_2$, $CO_2$, and $H_2O$ can be expected to produce surface organic matter. However, $N_2$ and $CO_2$ will remain in the gas phase at all times. If this model is valid, a surface landing presents an engineering problem of a magnitude never encountered before.

Table I

PARAMETERS RESULTING FROM GREENHOUSE MODEL "B"

| Parameter | Minimum | Maximum | Most Probable |
|---|---|---|---|
| Surface Temperature (dark side) | (Drake) $540^{\circ}$ K (at pole) | $640^{\circ}$ K | 610-$640^{\circ}$ K |
| Surface Temperature (light side) | $700^{\circ}$ K | $800^{\circ}$ K | $750^{\circ}$ K |
| Temperature at Cloud Top | --- | --- | $234^{\circ}$ K |
| Albedo | 0.6 | 0.76 | 0.76 |
| Cloud Top Height | 60 km | 100 km | 80 km |
| Water Content | 0% | Possible at Pole | Insignificant |
| Surface Pressure | 30 atm | Several 100 atm | 50 atm |
| Cloud Top Pressure | 90 mb (dark side) | 0.6 atm (670 mb) (light side) | Dependent on Hemisphere |
| Surface Wind Velocity | 0.3218 km/hr | 0.4827 km/hr | Very light |
| Height of Occultation | 107 km | 163 km | 135 km |
| Occultation Temperature | $195^{\circ}$ K | $216^{\circ}$ K | $203^{\circ}$ K |
| Occultation Pressure | $2.3 \times 10^{-3}$ mb | $2.9 \times 10^{-3}$ mb | $2.6 \times 10^{-3}$ mb |
| Density (gm/cm$^3$) | $1.325 \times 10^{-3}$ (cloud top) | $2.607 \times 10^{-2}$ (surface) | $6.5476 \times 10^{-3}$ (in cloud layer) |
| Molecular Weight | 29.6 | 29.6 | 29.6 |
| Sp. Ht. Ration | 1.347 (surface) | 1.4 (cloud top) | 1.389 (in cloud layer) |
| Speed of Sound (km/sec) | 0.3056 (cloud top) | 0.5278 (surface) | 0.4166 (in cloud layer) |
| Value of $\alpha$ where volume mixing ratio is $\alpha$ $CO_2$ to $(1-\alpha)N_2$ | 0.5 | 0.20 | 0.15 |

(Ref. 2, 13, 14, and 15)

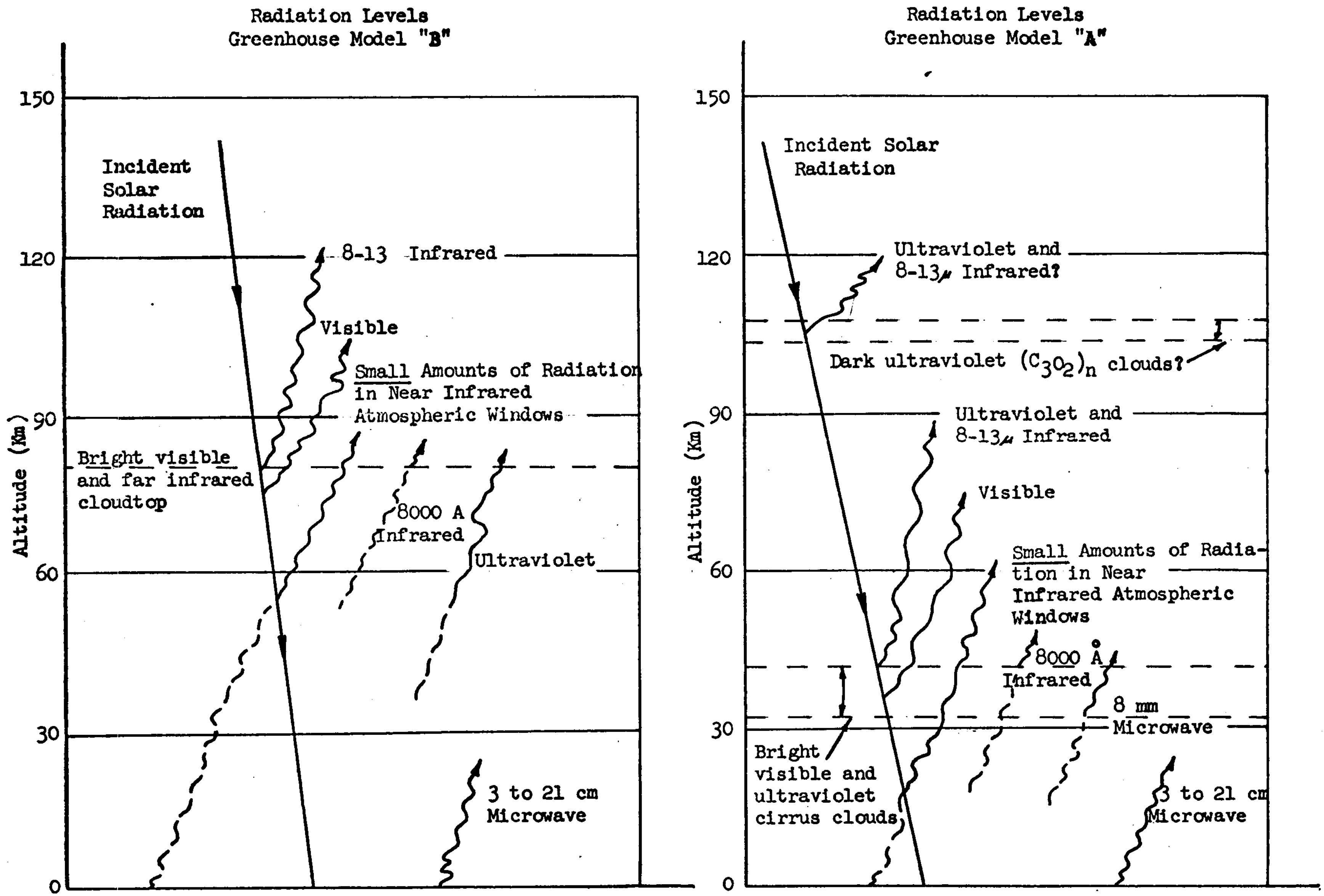


Fig. 1 COMPARISON OF GREENHOUSE MODELS "A" AND "B"
(RADIATION LEVELS)

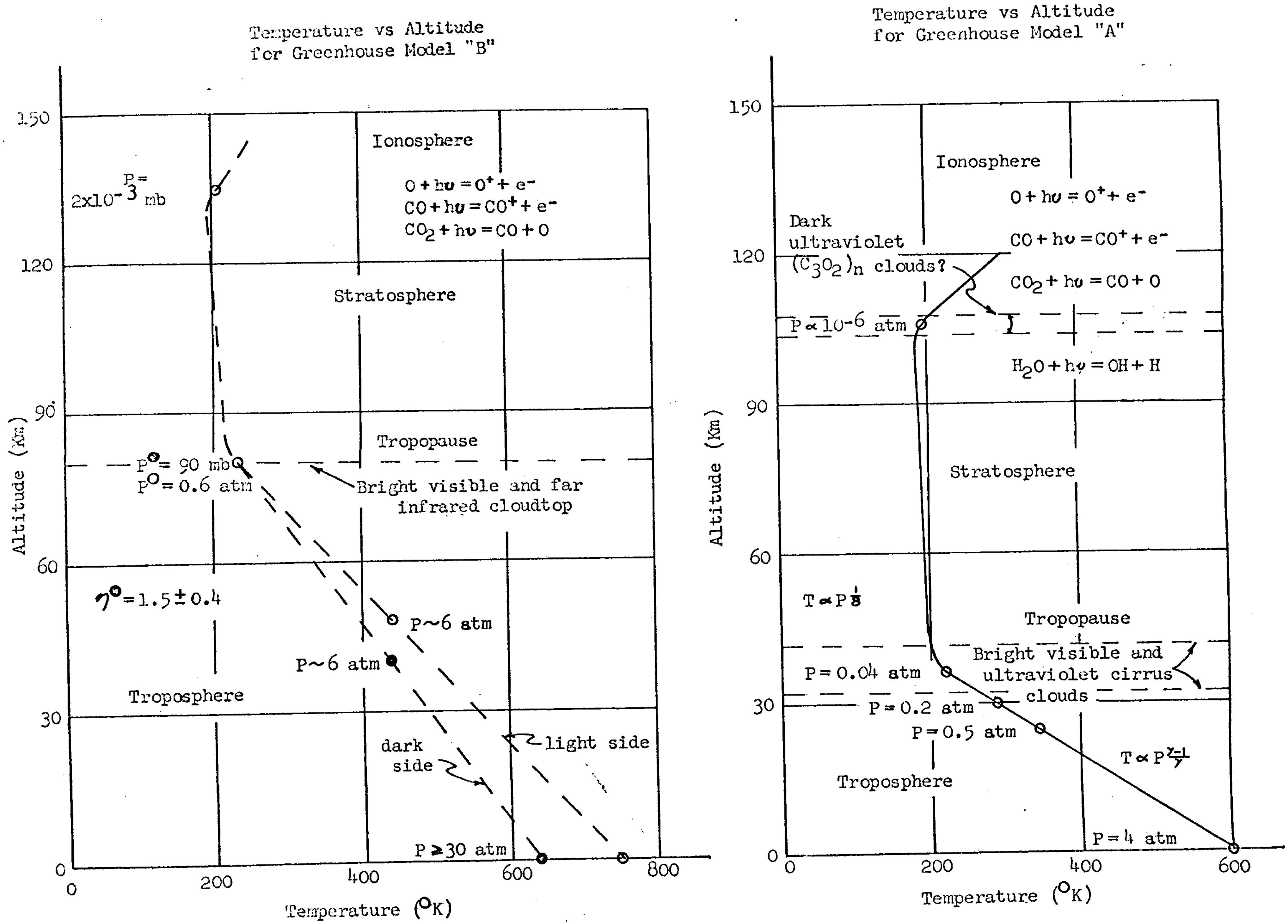


Fig. 2 COMPARISON OF GREENHOUSE MODELS "A" AND "B"
(TEMPERATURE VS ALTITUDE)

## REFERENCES


1. Spinrad, Hyron, "A Search for Water Vapor and Trace Constituents in the Venus Atmosphere," Jet Propulsion Laboratory Technical Report No. 32-256, October 1, 1962.

2. Sagan, Carl, "Structure of the Lower Atmosphere of Venus," Icarus, Vol. 1, pp. 151-169, 1962.

3. Sagan, Carl, "The Planet Venus," Science, Vol. 133, Issue 3456, pp. 845-858, March 24, 1961.

4. Sinton, William, Lowell Observatory, "Venus Atmosphere - Ice-Crystals and Water," Presented at the NSF-NASA-VPI Conference on Physics of the Solar System Re-entry Dynamics at the Virginia Polytechnic Institute, Blacksburg, Virginia, 1961.

5. Kaplan, Lewis D., "A New Interpretation of the Structure and $CO_2$ Content of the Venus Atmosphere," Planet Space Sci., Vol. 8, pp. 23-29, Pergamon Press, Great Britain, 1961.

6. Barrett, Alan H., and A. E. Lilley, "Mariner II Microwave Observations of Venus," Sky and Telescope, April 1963.

7. Ohring, G., "A study of the Meteorology of Mars and Venus," Geophysics Corporation of America Progress Report No. 3, July 1962.

8. Sagan, Carl, "The Physical Environment of Venus: Models and Prospects," Harvard College, Cambridge, Mass., 1961.

9. Ohring, George, and O. Cote', "The Meteorology of Mars and Venus," Geophysics Corporation of America Technical Report 63-6-N, Jan., 1963.

10. Mintz, Yale, "Temperature and Circulation of the Venus Atmosphere," Planet Space Sci., Vol. 5, 00. 141-152, Pergamon Press, Great Britain, 1961.

11. de Vaucouleurs, G., "Results of the Occultation of Regulus by Venus," Nature, Vol. 88, pp. 28-33, October 1, 1960.

12. Harteck, Paul, Robert R. Reeves, Jr., and Barbara A. Thompson, "Photochemical Problems of the Venus Atmosphere," NASA Technical Note D-1984, 1963.

13. Opik, E. J., "The Aeolosphere and Atmosphere of Venus," Journal of Geophysical Research, Vol. 66, Issue 9, pp. 2807-2819, September 1961.

14. Mintz, Yale, "The Energy Budge and Atmospheric Circulation on a Synchronously Rotating Planet," June 1962, Icarus, Vol. 1, 1962b.

15. Brown, J., "Venus Atmosphere Physical Properties," N63-15800, August 1962, Langley Research Center.

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