FINAL REPORT ON

"AN INVESTIGATION OF THE LOWER ATMOSPHERE OF VENUS"

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Abstract

On the basis of a discussion of the measurements which would be most relevant in the clouds of Venus, a number of instruments are suggested for further consideration, and two are discussed in some detail.

CHAPTER I: GENERAL REMARKS

A. The Design of an Investigation

Our knowledge of the Venus clouds is slight, and it is obvious that the first mission should seek the answers to only a few simple questions. Among these should be questions, the answer to which will facilitate the design of subsequent probes, such as, does icing occur? If the clouds consist of a condensible species it is very possible that in many places they would contain supercooled droplets (as is the case on Earth). In such an environment any vehicle would steadily accrete a thickening layer of "ice" which could deleteriously affect the performance of measuring probes. For example, windows may ice over; and a balloon designed to float in the clouds might eventually be forced down out of the region it was intended to sample.

Thus, emphasis should be placed not only on simple fundamental physical questions, but also on "technological" ones which bear on the design of later probes.

B. Redundancy of Measurements

Because it is impossible to be certain how a given device will perform in the Venus clouds, the measurements should be chosen so that they support each other; that is, to be somewhat redundant. A detailed consideration of almost any measurement on the clouds in this virtually unknown environment leads to some feeling of insecurity in view of the complexities of such measurements in our own atmosphere. A simple example of this relates to the icing phenomenon mentioned above. In Earth's clouds, supercooled water is extremely common. A temperature probe exposed to such a cloud is heated (by as much as 10 degrees C) as supercooled droplets impinge on it and freezing occurs. Under certain conditions, the temperature of such a probe can be used as an approximate measure of the concentration of supercooled liquid, but it may give an inaccurate measure of the temperature of the medium. In an analogous way, other measurements could give misleading results in the Venus atmosphere. This leads to the idea that redundancy should be sought after if not by making the same measurement in two different ways, at least by designing a set of measurements which are logically interlocking.

C. Limitation of Objectives

The range of temperature and pressure from the cloud tops to the surface is very great, and it cannot be expected that the significant atmospheric problems in the visible cloud layer bear much resemblance to those near the planetary surface. The choice has been made, therefore, to consider the problems of the visible cloud layer only, and to investigate methods of answering questions which would help in understanding this layer and so would relate to optical measurements made from Earth.

The leading questions concerning the cloud layer would appear to be:

1. Are the clouds stratiform or convective?
2. How thick is the cloud layer?
3. What is its optical density?

4. Do the clouds result from condensation?

5. Does "icing" occur in the clouds?

For the investigation of such questions as these, it is obvious that a descending probe would need to have a fall speed of the order of ten meters per second, and this is assumed throughout.

CHAPTER II: DISCUSSION OF THE LEADING QUESTIONS

A. Are the Clouds Stratiform or Convective?

The clouds of Venus have often been enviseaged as spherically symmetrical - that is, stratiform. Nevertheless, the possibility remains that they are in fact strongly convective, and that convective towers rise above a general cloud deck, as happens not infrequently on Earth. If indeed such complexity exists, some interpretations of optical data in which a stratiform structure was tacitly assumed may need revision.

If indeed the clouds are convective, it seems likely that they must be formed by condensation. As seen in the Earth's atmosphere, an inert cloud of particles diffuses under the influence of background turbulence and the vertical shear of the horizontal wind to form a flat sheet with only very slight gradients of density in the horizontal. A condensing species, however, supplies energy on the scale of the condensing volume, giving rise to various forms of conditional instability in which vertical motions create buoyancy which favors even stronger vertical motions, with the result that water clouds on Earth, quite unlike dust clouds, are characterized by strong gradients of all properties in the horizontal. Measurements which would reveal something of the nature of the upper surface of the clouds would, therefore, "interlock" with experiments designed to determine, for example, whether the cloud particles are volatile or not and also with measurements of horizontal gradients of cloud properties. Obviously, a consideration of cloud top observations will depend greatly on the results of the Venus-Mercury fly-by, and no specific recommendations are made concerning the investigation of the cloud tops, though the optical radar suggested below has the potentiality of being used for this purpose.

B. Cloud Depth and Optical Thickness

Questions (2) and (3) above - how deep is the cloud layer and how dense is it optically - are closely related, since the simplest method of measuring cloud depth is optical; indeed, the upper and lower boundaries could hardly be defined except in optical terms. The measurements of the scattering properties of the atmosphere should obviously be made in free air space rather than in a closed container since in this way the complications of icing and of inadvertently causing changes in the sample (by impaction or evaporation) are eliminated. These questions have, therefore, been considered primarily in relation to the dark side of the planet.

Many nephelometer configurations could be used; they differ from each other chiefly in regard to range and the degree of spatial discrimination which is sought. As has been argued above, if the clouds consist of an inert dust, they are probably stratiform and homogeneous in the horizontal; if of a condensed material, they are probably convective and heterogeneous in the horizontal. A measurement of optical properties made by means of a simple optical radar would, therefore, be greatly preferable to a measurement made by a short-range nephelometer in the immediate vicinity of the probe. By revealing something of the structure of the cloud in the horizontal, optical radar would provide more representative data, and would introduce a highly desirable element of redundancy. Such a device could also be capable of yielding some information about the nature of the upper surface of the cloud, and also of its lower boundary, where phenomena analogous to rain showers may well occur. The design of a simple optical radar is further discussed in Chapter III.

C. Are the Clouds Formed by Condensation?

In a cloud which has formed by condensation, the vapor pressure of the condensing species is likely to be close to the saturation vapor pressure. In terrestrial clouds this is true to within a few percent. If this situation is disturbed - for example, as a result of the mixing of air of different properties - it is re-established (on Earth) with a time constant of the order of ten seconds; it would appear very reasonable to assume that the atmosphere within the clouds of Venus - if they are formed by condensation - is close to saturation with respect to the condensing species.

There are, therefore, two general ways to examine this question: by conducting measurements on the cloud particles, or on the vapor. If a sample of the cloud air is heated or compressed, the cloud droplets will evaporate, and this could be detected optically. Once the volatile particles have been removed by evaporation, if the non-volatile particles were removed for example by an electrostatic precipitator, it would be useful to recondense the vapor to form a frost or dew on a cooled surface. If such a deposit were cooled deeply to ensure that it freezes, and were then remelted, it would be possible to determine the melting point of the condensing species, which would be of diagnostic value.

The output from a condensing apparatus of this kind would contain condensible vapors at partial pressures corresponding to the minimum temperature reached, and provided this temperature were below that of the mass spectrometer, could be used to supply it without risk of blockage due to condensation in the spectrometer leak or elsewhere. The design of an evaporator - condensor train is discussed in Chapter III.

If the clouds are formed by condensation, the particles are probably nucleated from the vapor by a pre-existing aerosol, as is the case on Earth, though it is just conceivable that they may be formed (at high supersaturations) by homogeneous nucleation. (If perchance the latter were the case, it would seem inevitable that the clouds would be very strongly convective indeed, since the onset of condensation would release a very large store of energy). Aerosol particles (Aitken nuclei) are ubiquitous in the atmosphere of the Earth; they originate from meteoritic bombardment, photochemical processes and from the surface, and their fall speeds are of order 10^{-4} to 10^{-3} cm sec^{-1}. It seems very likely indeed that they are widely distributed on Venus.

Under the influence of Brownian motion, Aitken nuclei continually coagulate with each other, and particularly with cloud particles. In terrestrial clouds, Aitken nuclei are absorbed by cloud drops at such a rate that their concentration diminishes with a time constant of the order of a few hours. If the clouds of Venus consist of n spherical particles of radius r cm per cm^3, and the visibility in the clouds is V cm, then, $Vnr^2 \sim 1$. Aitken particles are absorbed by the cloud particles at a rate of $4\pi NDnr$ particles cm^{-3} sec^{-1}, where N is the Aitken particle concentration and D is their diffusion coefficient. Thus, in cloud, the concentration of Aitken nuclei diminishes with a time constant of $(1/4\pi Dnr) = Vr/4\pi D$. Taking plausible values, such as: $V = 10^5$ cm, $r = 10^{-4}$ cm, $D = 10^{-5}$ cm^2 sec^{-1} this indicates a time constant of about a day.

If the cloud particles consist of liquid droplets, they must be expected to coagulate with each other under the influence of Brownian motion, electric fields, and differences in fall-speed in the gravitational field of the planet. Thus, a process analogous to that by which terrestrial clouds form precipitation seems likely to be occurring. The larger droplets formed by coagulation would then carry down to levels below the cloud layer a steady flux of Aitken particles. This "precipitation" would evaporate at some level, no doubt far above the planetary surface, releasing aerosol particles into the free air. However this occurs, it seems very likely that if the clouds are formed by condensation, they act as a trap for Aitken particles (as well as for gases which are soluble in the condensed species), the associated "hydrologic cycle" continually transporting them towards the surface of the planet, with the probable result that there is a marked discontinuity in Aitken nucleus concentration at cloud top level, as on Earth, where it often decreases by an order of magnitude over a few hundred meters. By contrast, if the clouds consist of dust, or are themselves a photochemically formed aerosol, such a discontinuity is less likely. Since the measurement of Aitken nucleus concentration is simple, it would be of interest to include this measurement.

D. Does "Icing" occur in the Clouds?

If the clouds of Venus consist in fact of supercooled droplets, the performance of any probe will thereby be affected; a thermometer may read several degrees high and windows may become obscured. The detection of icing in itself would be some diagnostic value in regard to the constitution of the cloud particles.

Perhaps the simplest method of detecting icing would be to compare the temperature indicated by a small thermometer probe with that derived from a measurement of the velocity of sound. If two-way measurements of the transit time of sound are made between a body suspended some distance below the probe, and the probe itself, both the velocity of the probe through the air, and that of sound could be measured with considerable accuracy. Treating the atmosphere as an ideal gas, the velocity of sound, V_s is given by: $V_s^2 = \gamma RT/M$, (γ, the ratio of specific heats; R, universal gas constant; T, absolute temperature; M, molecular weight of the atmosphere) and by making simultaneous measurements of V_s and T in the clear air above and below the clouds, that is in regions known to be free from icing (so that the directly measured temperature would be valid), it would be possible to evaluate γ/M independently of other knowledge of the constitution of the atmosphere. In the presence of a condensing vapor, the mixing ratio of which would vary with height, γ/M would not be exactly constant, and it might well be desirable to construct a simple theoretical model of the cloud layer to fit the data in order to be able to deduce T from V_s with improved accuracy. The temperature probe itself could be designed to give an independent indication that icing was occurring by making it in the form of a thermistor bead about 1 mm in diameter, mounted on a shielded, stiff fiber so that the frequency of transverse vibration of the fiber could be used to measure the mass accreted by the bead. Provision would be made to radiantly heat the bead in order to remove deposits periodically. The time variation of the bead temperature may also give significant information. For example, if a thermometer is exposed to a cloud of supercooled water droplets at a relative velocity of the order of 10 m sec^{-1}, as soon as it is wetted, it takes up the "wet bulb" temperature. But after the supercooled water skin which forms on it begins to freeze, it is heated by the latent heat liberated as a result of nucleation and freezing of newly arriving supercooled droplets to a temperature above that of the medium. The temperature rise depends on the volume concentration of supercooled water; in no case, of course, will the temperature rise above the freezing point of water. Temperature excursions such as these could give quite clear evidence of the presence of supercooled liquid, and may make possible a determination of its equilibrium freezing point and give a rough indication of its concentration. The frequency of oscillation measurement would redundantly indicate the same quantity.

If microphones are used to measure sound velocity, it would be possible to design the lower one (which could be remote from parachute noise) to detect meteorological sounds, should such be present. The a priori probability that the microphone would detect raindrops, thunder or aeolion tones generated at the surface of the planet is of course low, but if it did, the information provided would be of the greatest interest and of a kind not otherwise available; the measurements made on a descending probe tend to be purely local in nature and conspicuously lacking in the power to carry information concerning the surroundings of the probe. If the velocity of the probe relative to the air is found as described above; it would be of great interest to compare this velocity with a measurement of the rate of change of pressure using a sensitive variometer - that is, a leaky aneroid barometer. Such devices can measure quite small vertical velocities (with respect to the planet surface) provided they persist for periods of some seconds. By means of such a comparison, some idea could be gained of the vigor of convection in and below the clouds, and hence of the vertical flux of heat due to convective overturning.

III. TWO RECOMMENDED INSTRUMENTS

A. The Evaporator - Condensor

1. The Evaporator

Consider an evaporation apparatus in the form of a vertical tube, protruding below the probe; and suppose that heating elements within the tube, close to its inlet, dissipate heat into the gas stream. The concentrations of cloud particles of all sizes will be sampled correctly only if the gas enters the inlet isokinetically, that is, at a velocity relative to the probe which equls its fall speed. This can be achieved simply by using a venturi-type exhaust for the system and arranging the internal flow so that the pressure drop is proportional to the square of the gas velocity. If the gas is heated ($S^{o}K$) above ambient temperature, particles immersed in it will begin to evaporate. Provided that S is large enough (e.g. $10^{o}K$), the vapor pressure over the particles may be taken as the saturation vapor pressure over a plane surface of the same species, that is, the effects of curvature and of a dissolved nucleus which liquid particles may contain may be neglected. Under the same condition (S large enough), the increase in the mixing ratio of the vapor consequent on the evaporation of the particles may also be neglected.

Under these conditions, a spherical particle of order $r = 10^{-3}$ cm evaporates according to $\frac{dr^2}{dt} \approx -2ES$ where $E = \frac{M^2LDe}{\rho(R^2T^3+\frac{M^2L^2De}{k})}$

(M, the molecular weight of condensing vapor; ρ, the density of the condensed phase; L, its latent heat; D, the diffusivity of the vapor; e, its partial pressure at saturation; R, the universal gas constant; T, the absolute temperature; and k, the conductivity of the carrier gas). For water drops at 270°K, $E \approx 5 \times 10^{-8}$ cgs.

Provided that the upward speed of the gas flow, V, is large compared with the terminal velocity of the droplets, (about $10^6 r^2$cm $\sec^{-1}$), it follows that, for an individual droplet $\frac{dr^2}{dz} = \frac{-2ES}{V}$. Thus, if r is 10^{-3} cm initially, and if $V = 10$ cm $\sec^{-1}$, $S = 10^{\circ}$K, a droplet of water will have completely evaporated by the time it has been carried 10 cm up the tube.

If a laser beam is arranged to pass down the tube, and if, at a number of points along the tube, the light scattered sideways is sensed (over a solid angle of order 1 steradian) a reduction in size of the particles as they move up the tube could be observed. Thus a discrimination could be made between condensible and non-condensible particles.

Because r^2 varies linearly with t or z, the life of a particle after it reaches $r = 1\mu$ is very short - for a water drop, with $S = 10^{\circ}$K, of order 10^{-2} sec. Thus cloud particles may be considered to be annihilated at $r = 1\mu$, that is, before reaching the Rayleigh scattering region. Above this size, the scattering from many particles of various sizes over a range of angles may be roughly approximated by assuming a constant angle-integrated cross section K_o for each. The flux of scattered light received by a sensor may then be written $f = \pi I K_o \Sigma r^2$ where I is the intensity of the incident beam. Thus $\frac{df}{dz} = \frac{2 \pi I K_o ESn}{V}$, where n is the concentration of particles which are still larger than $r \approx 1\mu$. If the clouds consisted partly of condensible, and partly of non-condensible particles, f would be expected to decrease linearly along the evaporator tube until some of the condensible particles had evaporated; finally, f would remain constant, when only the non-condensible particles were left. If the condensible species is otherwise indentified, for example by the mass spectrometer, the value of E can be calculated, and the concentration of condensible particles then estimated from the value of $\frac{df}{dz}$.

In view of the possibility of gaining useful quantitative data from the variation in the light scattered from the cloud as it moves up the evaporation tube, it is important to design the heater in such a way that few particles are removed from the stream by impaction. One way to achieve this would be to pass the stream in laminar flow through a group of short parallel tubes forming a honeycomb.

In the gas stream leaving the evaporator, the partial pressure of the condensible vapor will exceed that in the environment (which will be very close to saturation at the ambient temperature) because of the additional material derived from the cloud. This is usually a small increment in terrestrial clouds, and an estimate of it may be made as follows: If the species has been otherwise identified, the value of E is known, and hence n may be deduced from $\frac{df}{dz}$. The initial values of f yield an estimate of $n \bar{r}^2$, where $\bar{r}$ is a mean particle radius; hence $n \bar{r}^3$ may be calculated, giving an estimate of the mass concentration of the condensed material and of the increment of partial pressure resulting from its evaporation.

Design considerations for the evaporator would include supplying sufficient heat at the very tip of the entry tube to avoid the possibility of blockage by icing; and possibly a periodic reverse-flow flush of heated gas from a bottle to further ensure against blocking.

2. The Condensor

If the clouds contain a non-volatile dust, these particles will still be present in the gas stream emerging from the evaporator. Even if the clouds consist entirely of a condensible species, it is very likely that the cloud particles will contain non-volatile "Aitken" particles which may have served originally to nucleate the cloud particle, or may have been absorbed by it. It is desirable to remove all particles from the stream before it enters the condensor; this is desirable also in relation to the mass spectrometer, which may derive its supply from the stream leaving the condensor, in order to avoid leak blockage. For the small flow rates being considered, the removal of essentially all particles from the gas stream does not pose a difficult problem: a choice could be made between an electrostatic precipitator and a filter system. The electrostatic precipitator would offer only a trivial resistance to gas flow compared with the filter, but introduces the slight risk that the corona discharge by means of which the particles are charged may result in the generation of traces of chemical compounds which were not present in the cloud.

Suppose that the gas stream from the evaporator (and precipitator) passes into a tube in which the temperature decreases more-or-less linearly. Condensation will tend to occur at and beyond the point where the stream has cooled to its dew (or frost) point. The condensate would have optical scattering properties very different from those of the substrate, especially in near-grazing incidence lighting. The basic problem is to ensure reliable and reproducible nucleation of the condensing droplets or crystals. If particles were permitted to enter with the gas stream, some would become deposited on the cooled surface, and could confuse the experiment by nucleating the growth of the condensed phase even at points where the vapor was not saturated. Some preliminary experiments have indicated that either freshly cleaned mica or gold-plated copper would provide a uniform and reproducible substrate for nucleation in the absence of contaminating particles.

A photo strip sensor would be used to detect the point at which condensate appears, perhaps by using grazing illumination. A known gradient of temperature having been established along a flat tube (say, 10 cm long, 1 cm wide and 0.3 cm deep), deposition of the condensible species would begin when the vapor became saturated. Thus, the temperature at which the condensible vapor is saturated is known; if the species is otherwise determined, its saturation vapor pressure at that temperature should be in agreement with the estimate of the partial pressure of the vapor in the gas stream leaving the evaporator. Optical sensing would imply the need for a transparent top for the tube, which would have to be kept a few degrees warmer than the lower surface forming the substrate for condensation or sublimation.

A possible ancillary experiment of some importance would be conducted by cooling the tube to a temperature low enough that any probable substance would freeze. The tube would then be sealed off and warmed. By means of optical sensors, the temperature at which melting began could be observed provided that its optical scattering properties differed sufficiently from a dew or a layer of liquid.

If the depth of the gas stream in the condensor is y, the "time constant" for diffusion of heat or of a vapor through the layer is of order $y^2/\pi^2 D$ where D is the relevant diffusivity. If the stream velocity is v, then $vy^2/\pi^2 D$ should be of the same order as ε, the resolution of the optical detectors. For heat, and for many vapors, $D \approx 0.2$ cgs and ε may be expected to be of order 0.1 cm. Hence vy^2 should be of order 0.2 cgs and for example, $y = 1/2$ cm, $v = 1$ cm $\sec^{-1}$. A suitable channel width would be 1 - 2 cm, so that the gas stream should carry a flux of order 1 cm^3 $\sec^{-1}$.

As the probe falls, the temperature of the in-flowing sample increases at the rate of 0.1°K $\sec^{-1}$. The evaporator and condensor would be most simply designed if they operated at constant temperatures. The evaporator might operate first at 300°K, the condensor providing a gradient from 300°K to 200°K. When the probe approached the 300°K level, it would be necessary to change over to a second train in which the evaporator was at 400°K and the condensor gradient from 400°K to 300°K. Alternatively, the evaporator could be arranged to operate at a constant temperature rise, of the order of some tens of degrees. Since the gas stream is not large enough to dominate the temperature of the evaporator tube, it would be necessary to supply heat to the tube walls as well as to the incoming gas stream. The condensor could similarly be programmed to provide a gradient from the variable condensor temperature to 100°K below it, though this would be more difficult than in the case of the evaporator, since cooling is involved. As the condensor requires gas flow of the order of only 1 cm^3 sec^{-1}, it may be more convenient to accept only a fraction of the flow from the evaporator for processing in the condensor. The remainder of the flow might well be utilized for the melting point experiment in a separate chamber.

B. A Simple Optical Radar

1. Introduction

A GaAs optical radar experiment is described which would provide information on vertical and horizontal stratification and optical density of clouds. The instrument is designed to be mounted on a large probe as described by Ainsworth, 1970 and Marcotte, 1970.

Due to limitations on weight, power and transmitter bit rate, a relatively simple scheme should be used. The probe is expected to be spinning as it descends. This motion will provide the horizontal scan. Vertical scanning will be taken care of by the vertical motion. The probe descends by parachute from an altitude of about 70 km above the surface of the planet (the altitude of the cloud tops). While on the parachute the probe descends at rates of 3.5 to 15m/sec for 1 hour. The probe is to be jetisoned at about 50 km altitude after which it will fall at rates of 15 to 80 m/sec. Total descent time is 1.5 hours.

One example of a two-mode nephelometer - lidar which will meet the space, weight, and volume requirements is discussed below. About 1800 measurements (1 measurement every 2 sec.) could be taken of backscatter. One mode of operation (nephelometer mode) consists of measuring the average total backscatter from near the probe to the maximum range of the lidar averaged over 8 sec. (two revolutions for a spin rate of 15 rpm). The other mode would be a lidar mode in which a small field of view sector (9^{o}) would be examined over a 0.1 sec. interval. Three range cells could be picked, for example 0.1 to 0.5 km, 0.5 to 1.0 km and 1.0 to 5 km. The signals from each range cell constitute separate measurements resulting in 4 total measurements in each set. The sequence would be to average the nephelometer signal for 7.9 sec and then take one lidar look for 0.1 sec. The 4 measurements would then be processed and sent back to Earth at the rate of 1 set every 8 seconds corresponding to a vertical descent of 24 to 120 m. A simplified block diagram of the instrument is shown in Fig. 1. The small weight and volume are made possible by the use of microcircuitry.

The two-mode operation allows the determination of both horizontal and vertical layering of the cloud structure. A higher data rate would be desirable; however 1 set of measurements every 8 sec. should be sufficient to provide some worthwhile information on cloud structure. Additional range cells could be used but at the expense of data rate.

2. Lidar System Description

(a) Transmitter - A pulsed GaAs laser array will be used as the transmitter. Arrays are available which emit up to 2000 watts pk at 5000 Hz pulse rate. An array emitting 100 watts pk at 1000 Hz and 200ns pulse width should be adequate to accomplish the desired task.

An optical system will be used in front of the array to reduce the beam divergence angle. A field as small as $3^{o} \times 3^{o}$ has recently been obtained from a 30 W average power GaAs array (Eros, 1971).

A 9° x 9° beam is adequate for the resolution element desired. In order to avoid absorption from a water vapor absorption band centered at 0.94μ, the GaAs array can be tuned to shorter wavelengths by lowering its temperature. Alternatively doped GaAsP lasers emitting at shorter wavelengths may be used at room temperature.

(b) Receiver - The receiver will use a collecting lens of 5 cm diameter. A silicone avalanche detector will be used with an NEP of about 5×10^{-13} W $Hz^{-1/2}$. Simple microcircuit analog integrating and logic circuits will be used. One integrator can be shared for all three range cells for the lidar mode of operation thus eliminating some components. An integration time of 0.1 sec. is compatible with the angular field of the transmitter and desired spatial resolution.

An estimate of the number of backscattered photons received in the lidar mode can be made from the following equation:

$$N_R = \frac{N_T f \tau \sigma \rho L A e^{-2\alpha Z}}{Z^2}$$

where N_T = number of photons transmitted in a single pulse, f is the repetition rate, τ is the integration time, σ is the scattering cross section per particle, ρ is the particle number density, L is the length of the spatial resolution element, A is the receiver collector area, α is the attenuation coefficient (assumed constant along the path), and Z is the distance from the transmitter to the resolution element. The noise count for a gated receiver limited by detector noise is given by

$$N_N = \left[\left(\frac{NEP \Delta f^{1/2}}{h\gamma}\right) m \ \Delta t \ \right]^{1/2}$$

where Δf is the effective electrical bandwidth, hγ is the energy per photon, m is the number of gates and Δt is the gate width. We assume the transmission is reduced by a factor e in one km and arbitrarily pick an average particle size of about 1μ radius or a scattering parameter $2\pi a/\lambda = 6.0$. Then ρ can be calculated from $\alpha = \rho\, \kappa \pi a^2$ where κ is the total scattering function (Middleton, 1958) and is about 3.8 for this situation. Then ρ is $8.4 \times 10^8\ m^{-3}$. The scattering coefficient σ (Middleton) is $7 \times 10^{-13}\ m^2/ster$ for scattering at 180°. Using the following values:

$f = 10^3$ pps

$\tau = 0.1$ sec.

$\sigma = 7 \times 10^{-13}\ m^2/ster$

$\rho = 8.4 \times 10^8\ m^{-3}$

$L = 400m$

$A = 1.97 \times 10^{-3}\ m^2$

$\alpha = 10^{-3}\ m^{-1}$

$Z = 1000m$

$N_T = 100\ (w) \times \frac{1}{h\nu(J)} \times 200 \times 10^{-9}$ sec. $= 9.05 \times 10^{13}$ photons

the number of received photons at the detector is 4.2×10^6 photons and assuming an NEP of $5 \times 10^{-13} W/Hz^{1/2}$ and 100 gates 200 ns wide the noise count from detector dark current is only 4.2×10^2 photons. Therefore, signals received by an instrument on a night time probe would not be limited by dark current shot noise. Shot noise due to brightly illuminated clouds is of more concern for a daytime probe. The worst possible case would be with the receiver looking at the cloud tops diffusely reflecting direct solar radiation. An estimate of the optical power in a 100 Å bandwidth reaching the detector in this situation, assuming an incoming flux of 7.9×10^3 Wm^{-2} μ^{-1} and an albedo of 0.85, is 8×10^{-4}W or 2×10^{12} photons in 0.1 sec. The S/N ratio defined by $N_R/N_{BG}{}^{1/2}$ is still >1; however, there is some danger of non-linear operation of the detector at this point. As the probe falls into the clouds however, the background radiation should decrease rapidly. The technique should give dependable signals well below the cloud tops for a daytime probe, however, more data would be obtained for a probe entering at night.

An estimate of the electrical power required is less than 2W and volume of 100 to 150 in.^{3}. The laser power can be periodically checked with an auxilliary circuit using the probe programmer if sufficient programmer circuits are available.

IV. CONCLUSION

The following instruments are recommended for further consideration for the cloud layers of Venus:

(a) A simple optical radar to sample the backscattering properties of the clouds up to a few kilometers from the probe. This device would yield more representative data on cloud optical density than a nephelometer; it would detect horizontal variability in the clouds, which relates to their dynamics and constitution; and it could be used to study the nature of the upper and lower surfaces of the cloud layer. Estimated weight, 4 lb; volume, 150 in^3; power requirements, 2 watts. Practical for the first mission.

(b) An evaporator which would indicate whether the cloud particles are volatile in whole or in part. Provided that the chemical nature of the condensing material is known (for example, from the mass spectrometer), the evaporator would yield rough estimates of the number and mass concentrations of the volatile cloud particles. Estimated weight, 2 lb; volume, 40 in^3; power requirement, 5 watts. Practical for the first mission.

(c) A group of instruments indicating whether icing is occurring - a vibrating reed icing sensor, and a suspended microphone to measure the velocity of sound which can be used to give the true temperature even in the presence of icing. The same group of instruments would determine the velocity of the probe relative to the air; with the addition of a leaking aneroid to measure (dp/dt), the same group of instruments would determine the vertical velocity of air motions and hence give an indication of the vigor of convection. Estimated weight 3 lb; volume 20 in^3; power requirement, 3 watts. Practical for the first mission.

(d) A condensor which would accept the output from the evaporator and would measure the dew-point (or frost point) of condensing vapors, and could serve as a cold trap in the gas stream from which the mass spectrometer is supplied. A determination of the melting point of the condensed material would be possible. Estimated weight, 3 lb; volume, 80 in^3, power requirement, 10 watts. Speculative for the first mission.

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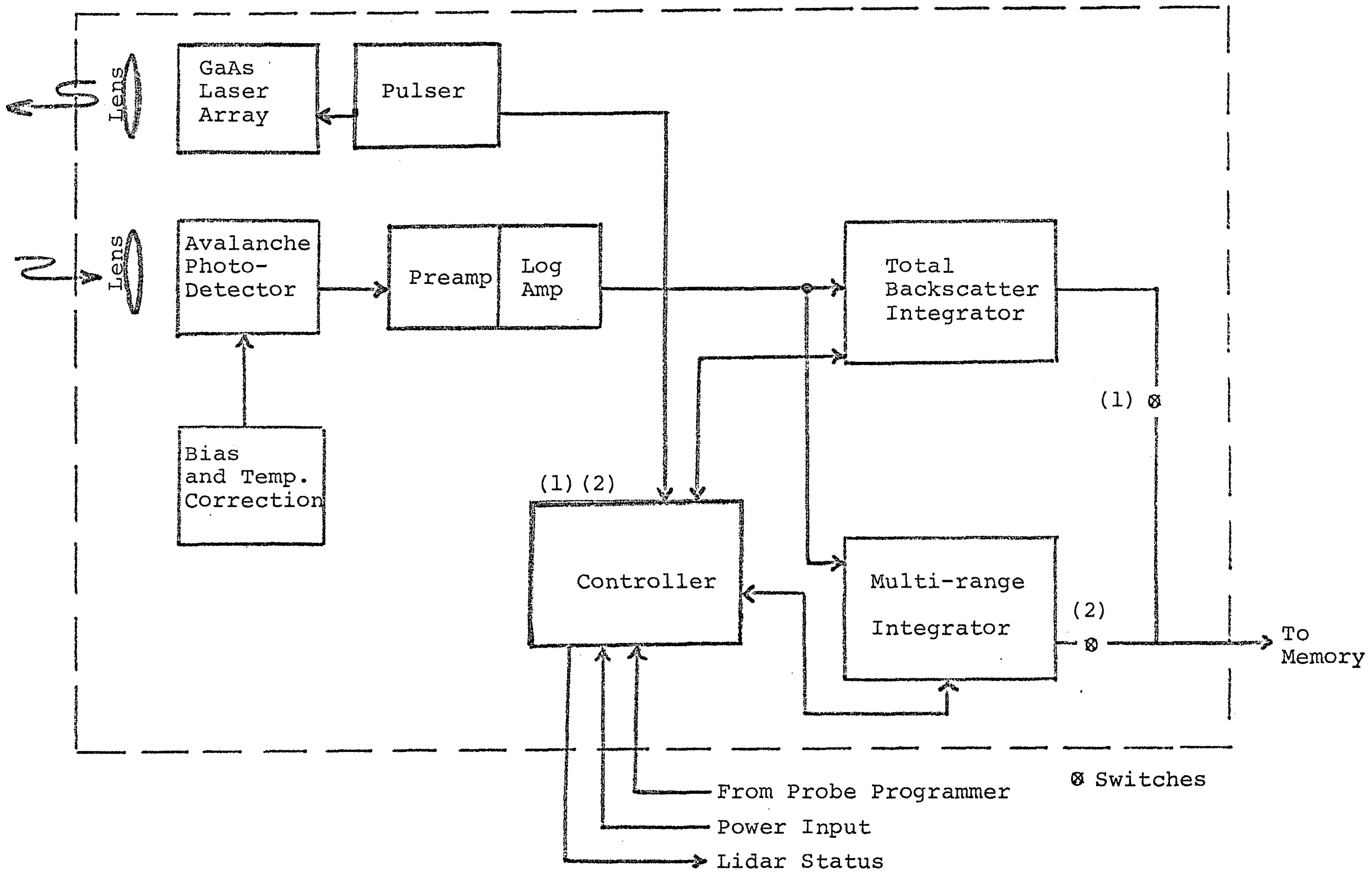

FIGURE 1. SIMPLIFIED BLOCK DIAGRAM OF LIDAR-NEPHELOMETER