SCIENCE RATIONALE FOR A DISCOVERY PROGRAM VENUS
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Introduction: The mix of gases in a planet’s atmosphere can provide many clues to the origin and
evolution of that planet (1-5). The capture and removal of atmospheric gases can occur through a
variety of processes over a range of time scales. Over millions of years, gases may have been
emplaced directly from the solar nebula during planetary formation, implanted by the solar wind, or
outgassed from the interior. Additionally, gases may also have been emplaced episodically through
cometary and meteoritic collisions following primary planetary accretion. Removal of atmospheric
gases may have occurred through mechanisms such as thermal loss, hydrodynamic escape, and
chemical reactions with the planetary lithosphere and with other atmospheric gases and particles.

Despite the success of a number of American and Soviet (now C.I.S.) probes in determining many
of the characteristics of the Venusian atmosphere, there are still major unresolved questions which
remain to be addressed. These questions, discussed below, can be best addressed by an atmospheric
probe instrumented for abundance measurements of the atmospheric constituents down to a sub-partsper-million or better precision. Such a probe might be carried out as part of NASA’s new Discovery
Program, a program of small planetary missions with tightly focused scientific objectives, designed to
promote diversity, breadth, and stability to the overall planetary program between major
exploration efforts.

Unresolved Atmospheric Questions: Four major questions regarding the Venuvian atmosphere
remain to be resolved: (1) What is the origin of the Syrtanian atmosphere and how has it evolved?
(2) What are the major and minor processes involved in the interaction between the atmosphere and
the lithosphere? (3) How does the sulfuric acid cloud cycle operate on Venus? and (4) How is solar
energy transferred to and from the Venuvian atmosphere?

Origin and Evolution: A fundamental problem in understanding the atmosphere of any planetary
body is determining the origin of the atmospheric constituents and how these constituents have
changed over time. Several sources may have contributed to the atmospheres of the terrestrial
planets, including Venus. These primordial atmospheres may have originated from the solar nebula
as the planets grew large enough to gravitationally retain them. More gas would be added over time
by outgassing from the interior through volcanic eruptions and tectonic activity. This type of
outgassing continues today on Earth, as it may on Venus, so that the atmospheric concentration of
certain constituents can be used to provide insight to the relative importance of present day volcanic
and tectonic activity on either planet. Other ongoing processes which may have added atmospheric
components since accretion include direct implantation of gas by the solar wind and addition of
volatiles by cometary and meteoritic impact. The latter mechanism plays a central role in the debate
over the origin of H2O in the Venuvian atmosphere and over its overall abundance in the crust,
mantle, and atmosphere (1-3). Of critical importance to the lattermost question are those
mechanisms for removing gases from the atmosphere which may include: thermal loss; hydrodynamic
escape; and chemical reactions with the surface rocks (1-4). In order to determine the true importance
of each of these processes, it will be necessary to obtain more accurate measurements of the total and
isotopic abundances of the rare gases He through Xe, as well as the abundance of hydrogen,
deuterium, and other isotope pairs such as 15N/14N and 13C/12C.

Thermochemistry/Lithospheric Buffering: A second area requiring further study relates to the
interaction of the Venuvian atmosphere with the crust. Carbon dioxide, the major atmospheric
constituent of the atmosphere, probably does not react extensively with the surface materials.
Instead, the majority of atmospheric/crustal interactions are likely to involve reactions of minor
atmospheric constituents such as water (H2O) and sulfur dioxide (SO2) with the surface rocks. The
high temperature (> 700 K) and pressure (≤ 100 bar) conditions at and near the Venuvian surface will
enhance the rate at which such reactions will occur. The conversion of diopside to anhydrite is one
such reaction that is likely to be important on the Venuvian surface (4). This conversion will only
take place in the presence of an SO2 buffer concentration of approximately 40 ppm. If the buffer
concentration exceeds 40 ppm then the reaction will accelerate, producing more anhydrite until a 40

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ppm concentration is restored. The atmospheric concentration of other species such as O₂, H₂, H₂S, H₂O, and COS will also reflect their importance in surface-atmosphere reactions. Data from the Magellan mission indicate the possibility of such surface-atmosphere reactions on Venus in recent times, with some highland areas exhibiting otherwise inexplicable variations in reflectivity and emissivity (6,7). In order to address the importance of these reactions, it will be necessary to measure the atmospheric concentration of these species, particularly below the maximum surface elevation of 12 km.

Sulfuric Acid Cloud Cycle: Sulfur compounds are not only important for surface reactions on Venus, but they also constitute the major species in the Venussian cloud deck. This deck extends primarily from 45 km altitude up to 70 km, with 10-15 km of thin haze above and below. All previous probes have commenced their science operations below 70 km, so the transition from the upper haze layer to the cloud deck has yet to undergo in situ examination. Cloud particles are thought to be produced by the photochemical oxidation of SO₂ at the cloud tops and by the condensation of H₂SO₄ near the cloud base. The H₂SO₄ particles appear to be the dominant species in the clouds at all levels, but smaller particles of unknown composition are also present at all altitudes. In addition to surface-atmosphere reactions, the exchange of different gas species also occurs at different elevations in the atmosphere. The process by which sulfur and its compounds are exchanged within the clouds and at the surface is called the sulfur cycle, and higher resolution measurements of the species at all elevations are necessary to understand the details of this cycle.

Solar Energy Deposition: Finally, the characteristics of the cloud deck in the 60-70 km altitude range must be determined in order to answer questions regarding the transfer of energy to and from the Venussian atmosphere. The major remaining unknown for this question is the identity of the particle or gas responsible for the absorption of solar radiation at wavelengths in excess of 320 nm. For wavelengths below 320 nm, upward flowing SO₂ can explain the observed ultraviolet contrasts and planetary spectral reflectivity (5). At higher wavelengths another absorber must be present and previous thermal energy profiles, UV contrasts, and spectral reflectivity measurements require that this absorber be present in the 60-70 km altitude range (5). Potential candidates for this absorber include both amorphous sulfur and molecular chlorine (5).

Instrument Payload: In order to adequately address the four major atmospheric questions described above a minimum science payload for a Venus Atmospheric Probe would include: [1] a neutral mass spectrometer to measure the chemical composition (including isotopic ratios) and physical state of the atmosphere as function of altitude; [2] a gas chromatograph to provide a profile of trace constituents including noble gases, sulfur compounds, carbon compounds, and water; and [3] an atmospheric structure instrument to determine mean molecular weight, atmospheric pressure, density, and temperature profiles to provide an altitude datum for the compositional measurements. The operation of these instruments should begin prior to 70 km in order to sample the top of the cloud deck, and should continue to the surface with sampling at 1 km intervals or better.

Discussion: A feasibility study of a Venus Atmospheric Probe mission that would carry the payload described above and would operate from 70 km to the surface has recently been completed by SAIC (8). The cost for such a mission is estimated to be $300 million in fiscal year 1992 dollars (8), in excess of the $150M maximum cost of Discovery Class missions. Operation at the high temperatures and pressures in the lowest 20-30 km of the Venussian atmosphere is a major cost driver, and by relaxing the requirement for probe survival at these altitudes it may be possible for the cost to approach that of a Discovery Class mission (8). By sampling from 70 km altitude down to 30 km, such a mission would still address 3 of the 4 major atmospheric questions discussed above. It is recommended that further consideration be given to the feasibility, cost, and merit of a mission with this set of scientific objectives.