ION-AEROSOL INTERACTIONS IN THE LOWER ATMOSPHERE OF VENUS

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Introduction: the atmospheric electrical environment on Venus
All planetary atmospheres are electrified to some extent by cosmic ray ionization, and Venus is no exception. There is increasing awareness that ion-aerosol interactions could modulate terrestrial radiative processes, and this possibility will be investigated for the Venusian atmosphere. The likelihood of a Venusian global atmospheric electric circuit (defined below) will also be discussed.

Venus' atmosphere is dense enough for ions and electrons formed by cosmic rays to rapidly produce ion clusters. Common predicted positive species are \( \text{H}_2\text{O}^+(\text{H}_2\text{O})_n \) (\( n = 3 \) or 4), \( \text{H}_2\text{O}^+(\text{SO}_2) \) and \( \text{H}_2\text{O}^+(\text{H}_2\text{O})(\text{SO}_2) \). Sulphate species dominate predicted negative ion species, and free electrons are also expected above 60km. Because of the ubiquity of the cloud cover (at ~50-70km), attachment to cloud particles is an important global ion loss mechanism, significantly reducing charged particle concentrations.

Could there be a global electric circuit on Venus?
A global atmospheric electric circuit needs, at the minimum, electrostatic discharge or charged particle precipitation balanced by current carried by mobile charged particles between a conductive ionosphere and surface. A global circuit causes transport of charged particles between different parts of the atmosphere. At the moment, the existence of a Venusian global electric circuit seems unlikely due to the lack of proof for electrostatic discharges. If lightning is unambiguously observed, then there is a good basis for the existence of a global circuit because of the presence of ions and electrons and a conducting ionosphere.

Electrification and particle formation
A potentially important mechanism for cloud formation at the bottom of the cloud layer is vapour condensing onto aerosol particles. The atmosphere is supersaturated with respect to sulphuric acid from 40km upwards, where \( \text{H}_2\text{SO}_4 \) vapour can condense onto hydrated sulphuric acid particles. As Venusian atmospheric ions are predicted to be sulphuric acid hydrates, appropriate conditions may exist for aerosols to form by ion-induced nucleation. The supersaturation required for ions to grow into ultrafine droplets by direct condensation can be determined using the Thompson equation. This equation describes the equilibrium saturation ratio needed for ion-induced nucleation to become energetically favourable. The equilibrium condition is defined at a saturation ratio \( S \), where \( r \) is radius, \( \rho \) fluid density, \( M \) the mass of the molecule, \( q \) charge, \( \gamma_T \) the surface tension, \( k_B \) Boltzmann’s constant, \( T \) temperature, \( r_0 \) the initial radius (all in SI units), and \( \varepsilon_r \) relative permittivity:

\[
\ln S = \frac{M}{k_B T \rho \gamma_T \pi r^2} \left[ \frac{2q^2}{r} - \frac{q^2}{32\pi^2 \varepsilon_r r^2} \left( 1 - \frac{1}{\varepsilon_r} \right) \right].
\]  

(1)

(1) can be used to assess if condensation of gaseous \( \text{H}_2\text{SO}_4 \) onto ions is likely to occur in the lower cloud-forming regions at ~40km. To calculate \( S \), \( \text{H}_2\text{SO}_4 \) concentrations and supersaturations determined from microwave absorption measurements are used. Temperatures were obtained from a model atmosphere. Surface tension, density and dielectric constant for ~100% sulphuric acid at 400K were estimated and extrapolated from existing data. (1) was then used to compute the saturation ratio needed for nucleation onto ions with 1, 2 and 5 electronic charges at a temperature \( T \), for the latitudes at which the saturation ratios were measured.

At 88ºS, supersaturation (SS) is expected at ~47km and 43km, but at the lower altitude the higher...
temperatures reduce the SS needed for activation. Figure 1 shows the solution of (1) at 395K. SS is never high enough to activate particles with one electronic charge, but doubly charged particles of radius 1nm can nucleate at SS=7%, and particles with 5 charges of radius 2nm are activated at SS=1-2%, relatively easily attained SS levels. The number of doubly charged particles can be estimated from the aerosol charge distribution arising from ion-aerosol attachment processes. The steady state charge distribution of a monodisperse aerosol population, represented as the ratio of the number of particles with charge \( j \), \( N_j \), to the number of neutral particles, \( N_0 \), can be given by

\[
\frac{N_j}{N_0} = x \frac{8\pi e_j a kT}{j e^2} \sinh \left[ \frac{j e^2}{8\pi e_j a kT} \right] \exp \left[ -\frac{j^2 e^2}{8\pi e_j a kT} \right]
\]

where \( j \) is the electronic charge, \( a \) the mean aerosol radius, and \( x \) is the “ion asymmetry factor”\(^7\). The charge distribution can be calculated for \( T=395K \) and typical ion properties at 40km. The mobility of positive ions was assumed to be 7% higher than negative ions, with no free electrons below 60km\(^1\). Positive and negative ions were assumed to exist in equal concentrations. The aerosol diameter at 40km was assumed to be 0.25\( \mu \)m. Substituting for \( a, T \) and \( x \) in (2) indicates that 84% of aerosols in this region carry some charge, with the most common single charge state being +1. The mean charge is +0.2, but, across the estimated charge distribution, Figure 2, \( j \geq 2 \) is relatively common with 54% of Venusian aerosols carry enough charge for ion-induced nucleation at supersaturations of 7%, and 7% of the aerosol population carries enough charge for nucleation at 1-2% supersaturation. These estimates suggest that it may be possible for gaseous sulphuric acid to condense onto ions and form aerosol particles.

![Figure 2 Steady state charge distribution on Venus aerosols with mean diameter of 0.25 \( \mu \)m at 395 K.](image)

Conclusions

- Venus almost certainly has active atmospheric electrical physics, though further measurements are needed to determine whether a global circuit exists. Because of cluster-ion formation in a dense gas, a global circuit could affect the location of charged particles and thus influence cloud or aerosol particle formation and lifetime. From a comparative planetology viewpoint, a Venusian global circuit with its permanent cloud would be interesting to compare to the effect of variable cloud cover on Earth’s global circuit.
- Formation of aerosol particles by heterogeneous nucleation onto ions may be possible. If this does occur then cosmic rays modulated by the solar cycle could potentially affect climate.
- Any charged particle and aerosol measurements should be simultaneous so that ion-aerosol interactions can also be investigated. Larger charged particles should be measured, as well as the ions that contribute to air conductivity. This could be achieved with a relaxation probe, like the Huygens PWA probe, but using a higher voltage to capture larger particles.

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