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Optical properties of Venus aerosol analogues

Michael J. Radke, Sarah M. Hörst, Chao He, and Marcella H. Yant
Johns Hopkins University, Baltimore, Maryland, USA (radke@jhu.edu)

Abstract

The past decade has seen the near-continuous observation of Venus' atmosphere from orbit with *Venus Express* and *Akatsuki*. These observations have produced a robust data set of cloud physical properties, including aerosol optical depth, particle size distribution, and particle refractive index. However, our interpretation of these properties is limited by our current lack of laboratory data about the compounds believed to comprise the clouds. We measured the optical constants (n + *i*k) of several proposed cloud species—both as pure solids and in acid solutions—from ultraviolet to infrared wavelengths. These data can be used to interpret the spectral features of Venus' clouds and understand possible compositional changes within the clouds.

1. Introduction

The Venusian cloud deck is a 20-km-thick global layer of sulfuric acid droplets with other trace components. This cloud layer absorbs fully half the incident solar radiation and is important for understanding the thermal balance, composition, and chemistry of the Venusian atmosphere [4]. A complex sulfur cycle sustains the extensive cloud layer, which includes particles of sulfuric acid, elemental sulfur, and an unidentified ultraviolet absorbing species [13]. The wealth of new ground-based and spacecraft data in recent years has transformed our understanding of the Venusian clouds and their temporal and spatial variability.

A variety of measurements have converged on a trimodal (or bimodal) model for Venus' clouds, e.g. [3], [5], [6], [11]. Reflected light phase curves as measured by spacecraft and ground-based telescopes are strongly sensitive to variations in particle size and refractive index. Many retrievals find a refractive index that is higher than possible for aqueous sulfuric acid, e.g. [10]–[12], suggesting that a higher refractive index component must be present in the clouds. It has long been suggested that other, non-sulfuric-acid, components are present in the clouds: elemental sulfur, sulfur oxide, iron chloride, and phosphoric acid, among others (see [13] for summary). However, most of these proposed "contaminants" lack refractive index measurements over the full range of wavelengths for which phase curves and/or polarimetry are available. Additionally, the wealth of new ground-based and spacecraft observations of Venus in recent years has revealed that both cloud particle size and refractive index are variable in time and location, e.g. [8], [9], [12]. These factors, combined with the inherent degeneracies within Mie scattering models, can result a wide range of retrieved cloud parameters from remote sensing observations that cannot be used to effectively interpret cloud composition and chemistry.

2. Methods

In order to address this issue, we have measured the optical properties of a variety of Venus aerosol analogues—both as pure substances and as mixtures with sulfuric acid. Complex refractive indices (n + *i*k) of pure solids were measured from 0.2–28.0 μm, and liquids and mixtures from 0.2–5.0 μm, using FTIR and UV-Vis spectroscopy.

We also investigated the production and chemistry of other possible cloud components by performing photochemistry experiments with Venus atmospheric gases in the lab. Laboratory experiments of sulfate aerosol formation have been performed with Earth-like atmospheres [1], [2], but similar investigations have, until now, not been performed for strongly oxidized Venus-like gas mixtures. In our new experiments, Venus analogue atmospheres composed of CO_2 and SO_2 to an energy source (UV lamp or cold plasma) to initiate photochemical reactions. Conditions of these experiments (295 K to 180 K and ~10 mbar) were most similar to about 80 km altitude on Venus, well above the main cloud layer. Our experiments generated both gaseous and solid products, which were collected for analysis with mass spectrometry and optical spectroscopy.

Experimental SO_2 mixing ratios were varied from parts-per-million to several percent, in order to encompass the full range of possible mixing ratios on

Venus—from the SO_2-poor upper atmosphere to SO_2-rich volcanic gases—in order to investigate the effects of SO_2 on aerosol formation.

3. Results

Preliminary photochemistry experiments performed with mixtures of SO_2 and CO_2 generated micron to millimeter size particles of yet undetermined composition. Analysis of these particles is difficult due to their low production rate and their quick reaction with terrestrial atmospheric gases.

Complex refractive indices were measured for possible Venus cloud species (and mixtures with sulfuric acid). These refractive indices can be used in Mie scattering models of Venus' clouds to help understand possible compositional changes in the clouds.

Future work may include measurement of optical constants at low temperature, spectroscopy of other possible Venus lower cloud components, and more photochemistry experiments with additional trace gases.

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