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ATMOSPHERIC CHEMISTRY ON VENUS: CURRENT UNDERSTANDING, OPEN QUESTIONS, AND UPCOMING MISSIONS. F. P. Mills^{1,2}, A. C. Vandaele³, E. Marcq⁴, K. L. Jessup⁵, A. Mahieux⁶ ¹Space Science Institute (Boulder, CO 80301), ²Australian National University (Canberra ACT, Australia), ³Planetary Aeronomy, BIRA (Brussels, Belgium), ⁴LATMOS/IPSL, UVSQ Université Paris-Saclay, Sorbonne Université, CNRS (Guyancourt, France), ⁵Southwest Research Institute (Boulder, CO), ⁶University of Texas Austin (Austin, TX).

Current Understanding: Venus, Earth, and Mars formed in a similar region within the solar nebula, which has been presumed to imply similar starting compositions [1]. Isotopic studies support this for Earth and Mars [2]. Dynamical simulations [3], however, leave the potential for significant differences. Venus today has comparable carbon and nitrogen budgets to Earth [1]. Its atmosphere is primarily CO₂ (96.5%) and N₂ (3.5%) [4]. Atmospheric chemistry, though, is controlled by trace species [5]. Venus' is depleted in H₂O but has a rich observed inventory of halides (HF, HCl), oxides (ClO, NO, OH, O₂, O₃, CO, OCS, SO, SO₂, SO₃, H₂SO₄), acids (HNO₂, HNO₃), polysulfur (S₃, S₄) and other compounds (H₂S, CS, a phosphorus-bearing gas) [6,7,8].

Atmospheric chemistry is dominated by the carbon dioxide, sulfur oxidation, and polysulfur cycles [Mills et al., 2007]. The carbon dioxide cycle includes photolysis of CO₂, transport and production of CO, O, O₂, and O₃, and production of CO₂, predominantly via chlorine-catalyzed processes [6,9]. The sulfur oxidation cycle includes oxidation of OCS and SO₂ to SO₃ and H₂SO₄, condensation of H₂SO₄, transport of H₂SO₄, and thermal decomposition of H₂SO₄ to regenerate SO₂ and H₂O [6]. This cycle produces the global sulfuric acid cloud layers and contributes to but is not the sole mechanism removing SO₂ as it is transported upward through the cloud layers [10]. In the polysulfur cycle, sulfur from photolysis of SO₂ and OCS undergoes (catalyzed) association reactions to produce S_x (2≤x≤8). S₈ can condense and be transported until it thermally decomposes, reacts with CO to form OCS, or oxidizes to SO₂ [6,11]. Polysulfur may contribute to the unidentified UV-blue absorption observed in the upper cloud [12,13].

Chemical regimes range from thermal equilibrium chemistry in the lowest scale height to photochemistry above the clouds. Heterogeneous chemistry and lightning are likely important as are interactions between chemistry and transport.

Open Questions: Within the broad understanding outlined above lie important, unresolved questions about the current and past composition and chemistry.

Observations show equatorial OCS decreasing with altitude at 30-40 km while CO increases [6]. Several reactions have been proposed to explain but only one

has been studied in the laboratory and it requires a means to generate S [6,10].

The cloud layers remain an enigma due to difficulties making remote measurements within them, conditions outside the range studied for terrestrial heterogeneous chemistry, and lack of modeling. In particular, observations above and below the cloud layers show SO₂ decreases with altitude much more than can be explained via oxidation to H₂SO₄ [6,10]. Dissolution in cloud droplets with hydroxide salts may explain this [14].

The interactions of transport and chemistry are only beginning to be studied in detail with 2D and 3D models [15,16,17,18,19]. Observed geographic and time of day variations in species abundances suggest these interactions are important [20,21].

Even the chemical mechanisms stabilizing CO₂ are not quantitatively resolved; models predict much more O₂ than the observational upper limit [6,10].

Upcoming Missions: DAVINCI+, EnVision, Shukrayaan, and VERITAS, in conjunction with accompanying laboratory, ground-based observing, and numerical modeling studies, will provide data needed to improve our understanding of these and other open questions.

References: [Grinspoon D. (2013) *Towards Understanding the Climate of Venus*, 17-22. [2] Burkhardt C. et al. (2021) *Sci Adv* 7, eabj7601. [3] Emsenhuber A. et al. (2021) *Plan Sci J* 2, 199. [4] von Zahn U. et al. (1983) *Venus*, 299-430. [5] Mills F. P. et al. (2021) *Space Sci Rev* 217, 43. [6] Marcq E. et al. (2018) *Space Sci Rev* 214, 10. [7] Mogul R. et al. (2021) *GRL* 48, e2020GL091327. [8] Mahieux A. et al., *under review*. [9] Marcq E. (2019) *Icarus* 319, 491. [10] Bierson C. J. and Zhang X. (2020) *JGR Planets* 125, e2019JE006159. [11] Pinto J. P. et al. (2021) *Nat Commun* 12, 175. [12] Mills F. P. et al. (2007) *Exploring Venus as a Terrestrial Planet*, 73-100. [13] Krasnopolsky V. A. (2016) *Icarus* 274, 33. [14] Rimmer P.B. et al. (2021) *Plan Sci J* 2, 133. [15] Yung Y. L. et al. (2009) *JGR* 114, E00B34. [16] Marcq E. and Lebonnois S. (2013) *JGR Planets* 118, 1983. [17] Gilli G. et al. (2015) *Icarus* 248, 478. [18] Parkinson C. D. et al. (2021) *Icarus* 368, 114580. [19] Lefèvre M. et al. (2022) *Icarus* 386, 115148. [20] Marcq E. et al. (2013) *Nat Geosci* 6, 25. [21] Encrenaz T. et al. (2015) *Plan Space Sci* 113-114, 275.