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Compositional Analysis and Optical Properties of Laboratory Simulated Meteor Smoke

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Balloon-based solar spectroscopy in the early 1980s detected anomalous light extinction around 440 nm, which was postulated to arise from a layer of particulate matter at $\sim$ 60 km altitude. Subsequent calculations suggested that spherical hematite (Fe_2O_3) particles of 20 nm radius, formed from the condensation of ablated meteoric iron which had oxidised in the atmosphere, could account for such a layer in the mesosphere. In spite of detailed modeling work on the formation of 'meteor smoke', no further atmospheric measurements have been made and no concerted effort undertaken to understand possible reaction pathways involved.

With this in mind, as part of the MAGIC project to determine the nature and properties of meteoric smoke in the mesosphere, we have conducted a series of laboratory simulations of smoke formation. Using gas-phase photochemical precursors to generate iron and silicon atoms (the dominant metal species released from ablating meteors) in the presence of O_3 and O_2, oxidation leads to the formation of high concentrations of individual nanoparticles which, via electric dipole and/or magnetic long-range forces, aggregate to form micron-size fractal chains. At the elevated metal atom concentrations used, visible smokes were observed in the reaction cell and material deposited on the cell windows.

Particle imaging by transmission electron microscopy (TEM) in conjunction with x-ray and electron energy loss (EELS) analyses revealed the respective particle/aggregate morphologies and compositions from different combinations of precursor species whilst electron diffraction was used to establish whether the smoke particles were crystalline or amorphous in nature. The Fe-Si-O system leads to the formation of chains composed of a mixture of amorphous iron silicate or fayalite (Fe_2SiO_4)

and polycrystalline quartz (SiO_2), whereas the Fe-O system results in hematite smoke composition.

Light extinction by these particles was measured as a function of wavelength in a long-pass optical cell, in combination with particle size distribution measurements. The results were used to verify literature values for the refractive indices of a number of candidate materials. Despite the chain-like nature of the smoke, calculations show that Mie theory provides a very good fit to the observed extinction profiles for hematite and fayalite.

Although a layer of fayalite particles of about 5 nm radius would explain the observed optical extinction in the atmosphere, a particle concentration of more than 10^6 cm^{-3} is required, which is at least 2 orders of magnitude more than predicted from current estimates of the interplanetary dust flux.