Constraining the Formation of Compound Chondrules in the Solar Nebula: Collision Experiments at Varying Viscosity (Temperature)

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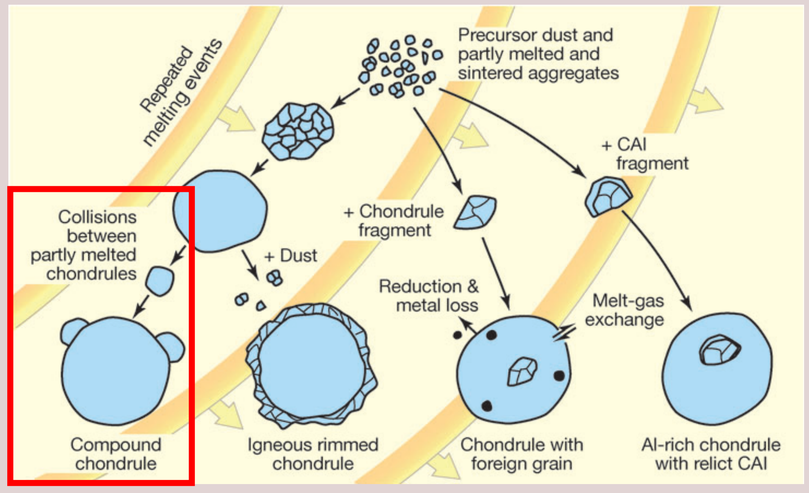
Introduction:

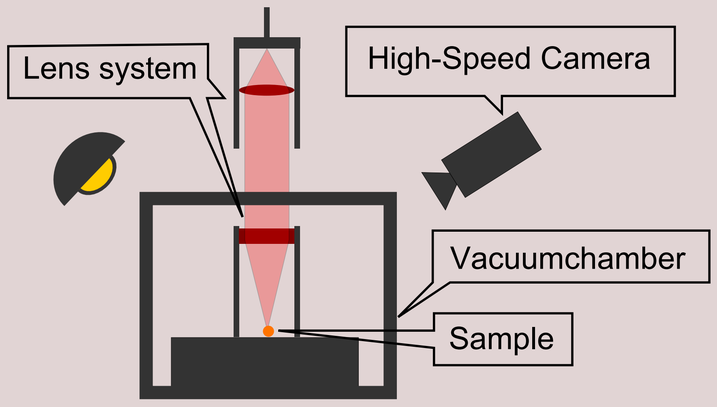
Compound chondrules e.g. are thought to have collided while still hot and viscous but further constrains are not known (Gooding and Keil (1981), Wasson et al. (1995)). Under what conditions do viscous particles stick together? Low viscosity might be beneficial for sticking at low collision velocities but if two droplets collide violently they just splash into numerous smaller droplets (Brenn and Frohn (1989)). Therefore, there will be different velocity thresholds separating collisional outcomes. Another question for rebounding viscous particles is what energy fraction remains as kinetic energy or how well do collisions damp an initial reservoir of fast particles. For chondrules at a certain temperature only a certain velocity range will result in collisions. Collisional outcomes of viscous particles have to be considered for chondrule and especially compound chondrule formation. For a given silicate at different (high) temperatures, viscosity is the obvious parameter that changes drastically.

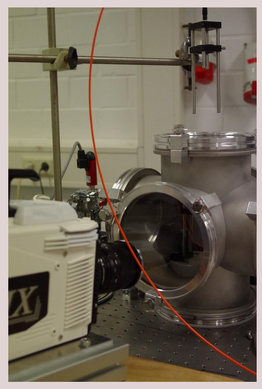


Evolution of chondrites in the Protoplanetary Disk (Scott, Edward R.D. (1997))

Setup and Calibration:

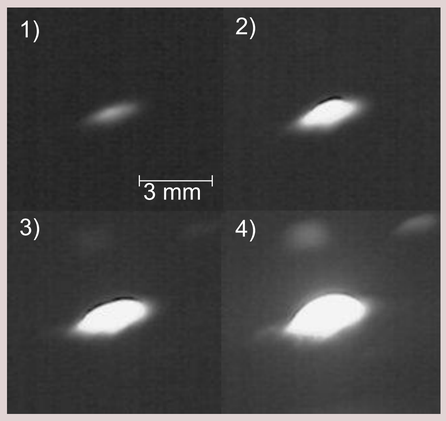
Our goal is the collision of heated or almost melted material analog to the chondrules. For the heating process we use a laser with a maximum optical output of 40 Watt. The material in use is basalt in form of small basalt chips which are either lying on a ceramic surface or mounted on small ceramic tubes.



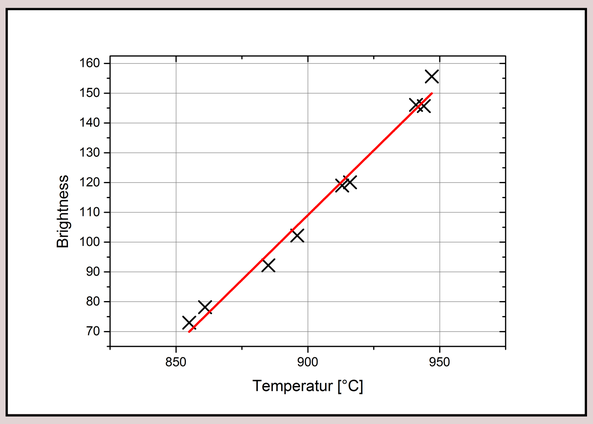


The first step of our experiment was the calibration of a high-speed-camera. In a series of pictures we determined the correlation of the brightness received by the camera and the measured temperature of the sample. This is convenient for further image processing as well as necessary since our thermographic camera is limited to a maximum temperature of 950°C.

Basalt chips



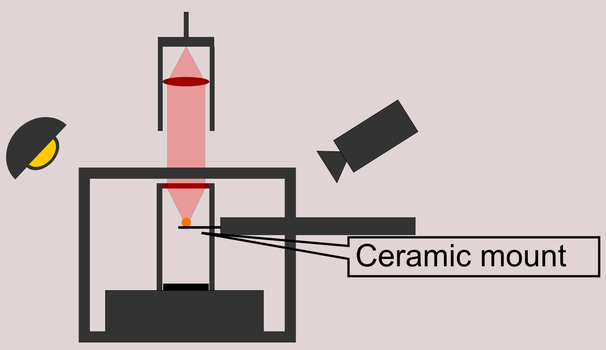
Basalt chip at increasing temperature

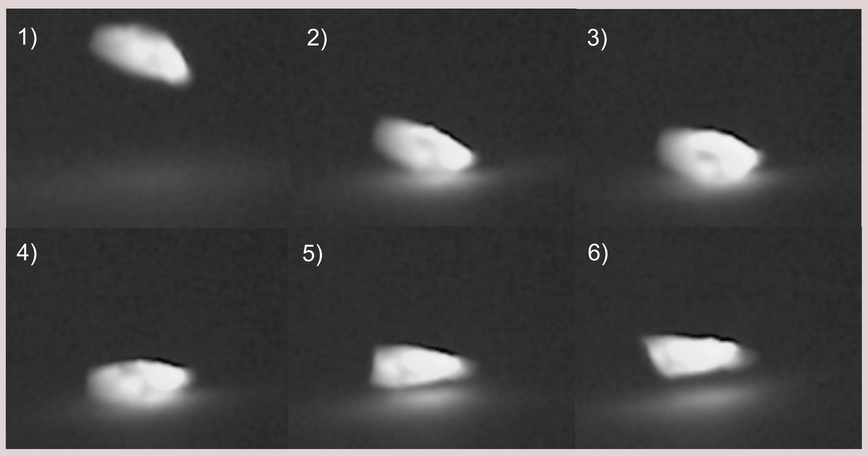


Correlation of temperature and brightness

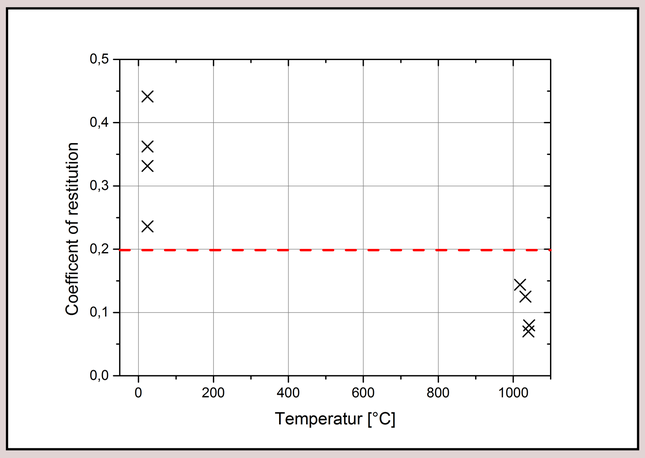
First collision experiments:

We further conducted collision experiments of small basalt particles (2-4 mm diameter) that were heated up on a ceramic mounting. After release the particle falls on a ceramic surface not further than a few centimeters resulting in a collision speed of roughly 0.8 m/s. The irregular shape of the particle results in a number of different collision outcomes and thus resulting in a large variation regarding the coefficient of restitution. However the results of our initial collision experiments show a notable decrease in the coefficient of restitution with temperatures of over 1000°C. The measured temperature is the mean temperatur of the surface explicitly touching the ceramic surface and not the often much higher core temperature of the particle.





Collision sequence



Coefficient of restitution at higher temperatures

References:
Scott, Edward R.D. (2007, Mai), Chondrites and the Protoplanetary Disk, Annual Review of Earth and Planetary Sciences, vol. 35, Issue 1, p.577-620.
Brenn, G., Frohn, A. (1989, July), Collision and merging of two equal droplets of propanol, Experiments in Fluids, Volume 7, Issue 7, pp.441-446.
Gooding J. L. and Keil K. 1981. Relative abundances of chondrule primary textural types in ordinary chondrites and their bearing on conditions of chondrule formation. Meteoritics 16:17–43.
Wasson J. T., Krot A. N., Min S. L., and Rubin A. E. 1995. Compound chondrules. Geochimica et Cosmochimica Acta 59:1847–1869.