SOME REMARKS ON THE DENSITY OF INTERPLANETARY DUST GRAINS

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ABSTRACT. The relevance of the bulk density as a physical parameter characterizing interplanetary dust grains is discussed. The various measurements which lead to a determination of this parameter are reviewed. The specific case of the collected interplanetary dust grains is considered.

The bulk density of interplanetary dust grains has been and is still a matter of controversy. This quantity cannot, in general, be directly measured; it is used to relate the mass and the size of a grain. This duality stems from physics itself as there are interactions sensitive to the mass (e.g., gravitational forces) while others are sensitive to the size or the cross-section (e.g., light scattering, radiation pressure, gas and plasma interactions). The measuring technics of the grains reflect this duality as, for instance, impact sensors are generally sensitive to the kinetic energy and thus to the mass, while optical sensors are sensitive to the cross-section. One sees that the density is not strictly speaking the relevant parameter, but what is needed is a relationship between mass and average cross-section.

1. SOURCES OF INFORMATION ON THE DENSITY

1.1. Lunar microcraters

The ratio P/D_c of the depth to the crater diameter is known to be a good indicator of the density of the impacting particle. After conflicting results, the situation was clarified by Le Sergeant and Lamy (1980) who based their analysis on 284 craters. They concluded that low-density grains ($\lesssim$ 1g/cm^3) are not detected, that grains in the diameter range 1 - 500 μm have densities of the order of 3g/cm^3 typical of silicates and that, below 1 μm, two components are present, one with the above density of 3g/cm^3 and the other with a higher density possibly indicating a metallic composition. It has been argued (e.g., Hanner, 1980; Fechtig, 1982) that the data of Nagel et al. (1976) indicates a "low-density" group ($\sim$ 1g/cm^3-. This is not correct as discussed by

R. H. Giese and P. Lamy (eds.), Properties and Interactions of Interplanetary Dust, 137–140.

Le Sergeant and Lamy (1980) as the ratio P/D_c of 0.4 for this group (or $D_c/P = 2.5$) implies a density of 2 to 2.5 g/cm^3. In fact, the calibrations of Vedder and Mandeville (1974) indicated for polystyrene projectiles ($\rho = 1$ g/cm^3) $P/D_c \sim 0.2$, a value significantly lower than that pertaining to the "low-density" group of Nagel et al.

With the exception of collected grains for which all physical parameters can in principle be measured, the P/D_c criterion yield a straightforward relationship between mass/density and cross-section/size, while being free of assumptions. Therefore, the above result may be regarded with an high level of confidence. However, crater formation by low-density aggregats has never been studied and it may be argued that either they form craters too shallow to be detected or they rapidly coalesce at impact and thus behave as smaller normal-density projectiles.

1.2. Meteors

Relating the quantities observed when a meteor penetrates into the Earth atmosphere to the original mass of the meteor and its density is far from being straightforward and in fact, requires many assumptions. The complexity of the physics which may not be accounted for by the classical equations (Hughes, 1978) as well as the uncertainty on various parameters probably preclude obtaining more than an order of magnitude for the density of the meteors.

For radio-meteors in the mass range 10^{-6} - 10^{-2} g, Verniani (1973) found a mean density of 0.8 g/cm^3. For photographic meteors whose masses are larger than $\sim 10^{-2}$ g, even lower densities (0.3 g/cm^3) were reported (e.g., Millman, 1976). Ceplecha (1967) and Benyuch (1974) have, on the contrary, obtained density in the range 1.4 - 4 g/cm^3.

The result of Verniani (1973) may certainly be questioned on the basis of the lunar microcraters data which overlap the lower end of his mass interval and which definitely do not support a density of 0.8 g/cm^3.

The whole question certainly needs to be revised. The physical description of meteor penetration has recently been improved by Pecina and Ceplecha (1984). They have not yet reported results for the density of meteors but Ceplecha (1983) already pointed out the importance of using "instant" atmospheric density profiles in comparison with standard atmospheres. Such progress should hopefully lead to a better estimate of the density of meteors in the near future.

1.2. The Helios data

The Helios sensors were not specifically designed to measure the density of impacting grains. However, the ecliptic sensor detected approximately twice less events than the south sensor although is was identical to the former except for a thin protective film against solar wind particles. Because of their orbital characteristics, these surplus events should have been detected by the ecliptic sensor. This question has received considerable attention and Grün et al. (1980) found that the front film has a discriminating effect w.r.t. the density of impacting

grains and concluded that 30 % of interplanetary dust particles have densities below 1 g/cm^3. This analysis calls however for several remarks.
i) The relevant calibrations performed by Pailer and Grün (1980) cover only the following ranges: 1.25 - 7.85 g/cm^3 for the projectile density, 10^{-13} - 10^{-10} g for the mass and 1.4 - 13 km/sec for the velocity. The range of velocities is probably too low, but more important, no experimantal results are avaible for $\rho < 1.25$ g/cm^3; henceforth, the interpretation of the Helios data is based on extrapolations.

The fact that the maximum densities are systematically less than 1 g/cm^3, down to 10^{-2} g/cm^3 (not to mention 10^{-5}) looks highly suspicious.
ii) It is clear from the study of Carey et al. (this volume) that, in the case of the perforation limit for particles with ρ = 1 g/cm^3 impacting aluminium foil, the Pailer and Grün (1980) equation gives the highest d/f or, in other terms, systematically favors low densities.
iii) After correcting for the difference in sensitivity between the ecliptic and the south sensor, the excess of impacts reduces to ∿ 1.4; a simple inspection of the experimental results of Pailer and Grün (1980) shows that this reduction of sensitivity may well be accounted for by particles having densities between 1.25 and 7.8 g/cm^3.

The above remarks suggest that the results of Helios for the density of interplanetary grains as reported by Grün (1980) must be considered with some precautions.

1.4. Collected interplanetary dust grains (IDG)

Collected IDG represent potentially the best source of information for the density. Although no direct measurements have been reported, estimates are possible based on composition and physical appearance and Brownlee (1978) indicated a range of 1 to 3 g/cm^3. The possibility of low-density concerns, however, only the small fraction (∿ 6 %) of chondritic aggregates - which are definitely not fluffy - the remaining 94 % having the bulk density of the minerals composing them. This is also the situation for meteorites whose density lies in the range 2.2 g/cm^3 (C1) to 7.85 g/cm^3 (Iron).

2. CAN LOW-DENSITY PARTICLES REALLY EXIST ?

An absolute constaint on the density of IDG comes from their composition. The bulk density of solid, non-volatile materials present in the solar system is larger than ∿ 2 g/cm^3 (ices are left out of the present discussion since icy grains cannot be present at 1 AU). With this condition, how far can the apparent density be reduced? I made a very simple investigation by scaling a 5 μm diameter chondritic aggregate of 0.4 μm "elementary" grains to a 25 mm diameter sphere made of pyrex spheres (density 2.5 g/cm^3) of 2 mm diameter and considered two extreme cases for which the cross-sections as well as the masses were perfectly defined so that the apparent densities could be calculed:
i) One outer monlayer of pyrex spheres yield an density of 0.63 g/cm^3 while the fraction of void amount to 75 %;

ii) Complete filling of the 25 mm sphere by the pyrex spheres yield a density of 1.65 g/cm^3, the fraction of void being 34 %.

None of the collected chondritic aggregates looks like the first extreme case and Brownlee (1978) was correct when he indicated a density larger than 1 g/cm^3. One could still further reduces the density by removing some of the pyrex spheres from the outer monolayer while retaining approximately the cross-section but not by much. The conclusion is therefore quite clear: an aggregate having a fraction of void as large as 34 % still has a density larger than 1 g/cm^3; only under extreme conditions with much larger fraction of void does the density becomes less than 1 g/cm^3 but it never becomes much less than 1 g/cm^3.

As the most direct analysis (lunar microcraters) and physical evidences lead to rejecting low densities for interplanetary dust grains while they are only supported by indirect methods (meteors) or extrapolations (Helios), it seems quite reasonable to accept this rejection.

Finally, the above simulation suggests a possible method to determine the density of the collected interplanetary dust grains whose shape is not too complicated. It consists in measuring the mass and the average of several cross-sections (from scanning electron microscope photographs). Then a mean size can be defined and consequently, a mean density can be determined.

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