DETERMINATION OF PARTICLE DENSITIES BY PENETRATION STUDIES

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Thin films are used in micrometeoroid experiments to shield the sensors from external noise sources. Because of the spin of the Helios spacecraft the ecliptic sensor is exposed to the Sun. Therefore a 3000 Å parylene film coated on one side with 750 Å aluminium protects the experiment against UV-radiation and solar wind particles. The south sensor is shielded from solar emissions by the spacecraft rim and therefore has an open aperture.

During the first 6 orbits around the Sun the experiment registered a total number of 168 micrometeoroids; 52 particles were detected by the ecliptic sensor and 116 by the south sensor. Due to their orbital characteristics these surplus particles should be observable also by the ecliptic sensor (Grün et al., 1979). Since they have not been detected by the ecliptic sensor it is concluded that the only instrumental difference between the two sensors, the entrance film in front of the ecliptic sensor, prevents them from entering it. Therefore an extensive simulation program has been carried out (Pailer and Grün, 1979). Table I gives a compilation of the projectile parameters used. The projectile density varies between 7.8 and 1.25 g/cm^3, the corresponding masses between 10^{-13} to 10^{-10}g and velocities from 1.4 to 13.3 km/sec.

Table I: Projectiles for penetration studies.

projectile material	density (g/cm^3)	mass range (g)	speed range (km/sec)
iron	7.85	$2\times10^{-10} - 5\times10^{-13}$	1.4 - 13.3
aluminium	2.7	$4\times10^{-11} - 2\times10^{-12}$	3.0 - 7.5
glass	2.4	$2\times10^{-10} - 6\times10^{-12}$	1.5 - 4.2
polyphenylene	1.25	$5\times10^{-11} - 3\times10^{-13}$	2.0 - 11.0

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Dust projectiles are detected by an impact plasma detector if their impact speed exceeds approximately 1 km/sec (Dietzel et al., 1973). If dust projectiles are decelerated upon film penetration below this speed limit, they will not be detected. Therefore, the reduction of impact plasma depending on deceleration by film penetration was investigated.

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 365–370.

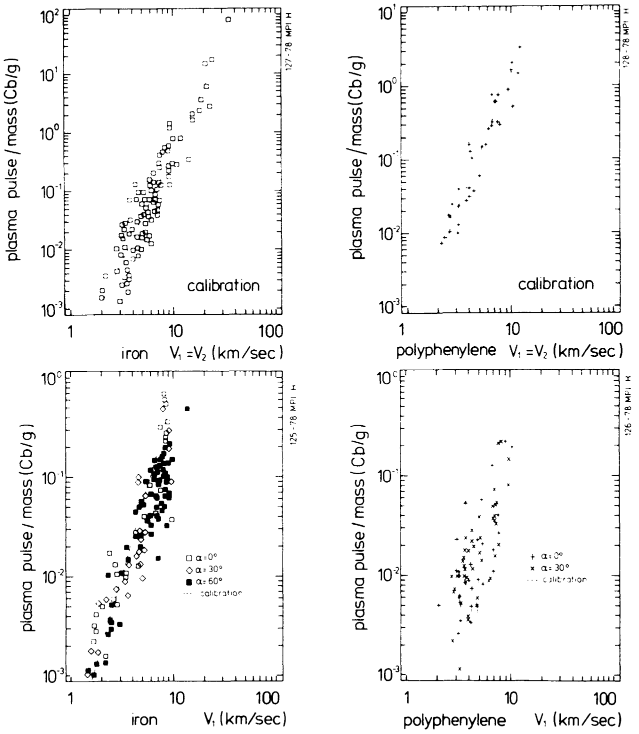

Figure 1: The plasma pulse normalised to the mass is plotted vs. v_1
upper panel: calibration (without film in front of plasma detector);
lower panel: measurement (with film in front of the plasma detector).

In Fig. 1 the change of impact charge produced by different projectile densities and different angles of incidence is shown. Only the results of iron, the highest density, and of polyphenylene, the lowest density, are shown because Al and glass gave intermediate results.

The four diagrams in Fig. 1 show the plasma pulse/mass plotted versus the projectile velocity in front of the film. For the upper diagrams a certain flight distance was divided exactly into halves by a grid. The charge produced upon impact of iron particles on a gold target at the end of the flight distance was noted. This measurement is called calibration. The same applies for polyphenylene which has the low density. For the lower diagrams the grid used for the calibration was replaced by the Helios film. This was mounted rotatable in order to simulate inclined incidence. Within the measurement the impact angle varied in 30° intervals from 0° to 60°. The dashed line represents the calibration. One sees no significant differences within the scattering of the measurement with iron particles in comparison to the calibration. This is due to the very small deceleration of iron projectiles. It is quite different for polyphenylene which has the low density. Such projectiles impacting at 0° and 30° show an attenuation of the plasma pulse by about a factor of 10. Polyphenylene projectiles impacting at 60° could not be detected behind the film.

This means that in general projectiles with low densities are discriminated against by the film.

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The lower diagrams showed only projectiles which were detected after film penetration. The mass and velocity diagrams in Fig. 2 include all projectiles which were shot onto the film. Here the

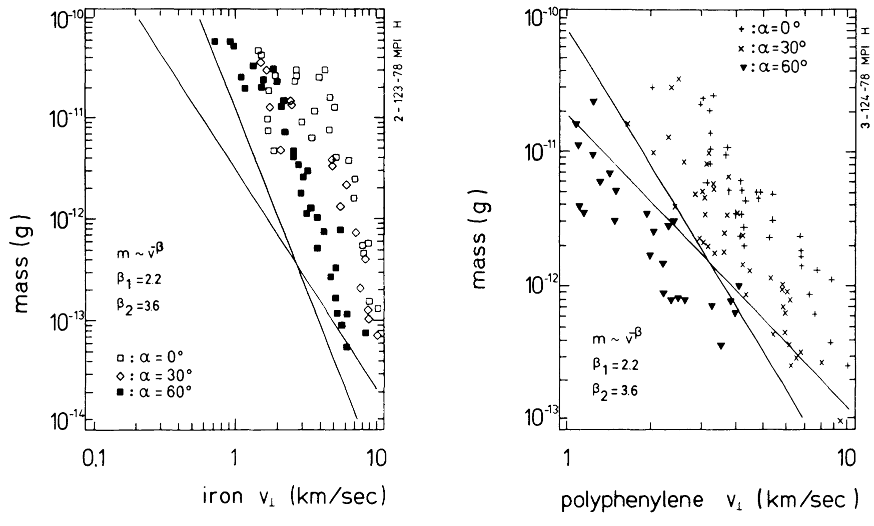

Figure 2: Mass and speed diagrams of iron and polyphenylene projectiles $v_\perp$ = cos α
—— : extreme cases of possible penetration limits.

speed means the component vertical to the film surface. The symbols represent impacts at 0°, 30° and 60°. Polyphenylene projectiles impacting at 60° could no longer be detected by the plasma detector. They are characterised by solid triangles. In the m-v-diagram the penetration limit lies somewhere between those projectiles impacting at 60° and those impacting at 30°. This is identified by extreme lines in the diagram. Above this limit polyphenylene projectiles penetrate the film and projectiles below this limit can no longer be detected behind the film. The left diagram shows the same data for iron projectiles. In this case all projectiles penetrated the film. Therefore, only an upper boundary for the penetration limit can be given. The lines have the same slopes as for polyphenylene. The difference in the penetration limits for polyphenylene and iron is due to their different densities. The penetration limit is defined by the projectile mass m_{pr}, speed $v_{pr\perp}$ and density ρ_{pr} according to

$$m_{pr} v^{\beta}_{pr\perp} \rho^{\gamma}_{pr} = \text{const.} \qquad (1)$$

with $\gamma \geq 1$ and β ranging from 2.2 - 3.6. A comparison of penetration formulae found in the literature (c.f. Pailer and Grün, 1979) resulted in a new formula:

$$m_{pr}^{0.40} v_{pr\perp}^{0.88} \rho_{pr}^{0.33} \frac{1}{\varepsilon^{0.06} \rho_t^{0.5}} = T \qquad (2)$$

with T = penetration thickness or crater depth (cm), ε = ductility of target material (%), ρ_t = density of target material (g/cm^3), m_{pr} = mass of projectile (g), $v_{pr\perp}$ = normal component of impact speed ($km s^{-1}$) ρ_{pr} = density of projectile (g/cm^3). This general formula describes penetration thicknesse or crater depth from 10^{-5}cm to 1 cm and is verified by experiments with target and projectile densities ranging from 0.9 to 19.4 g/cm^3, projectile masses ranging from 10^{-14}-1g. The speed ranges from 2 to 20 kms^{-1}. This information can be compared with the other information available from the experiment. One direct measurement is the total charge Q released upon impact. It depends on projectile parameters as

$$Q \sim m_{pr} v_{pr}^{2.7} \qquad (3)$$

If both equs.(2 and 3) are adjusted at v=20 km/sec, which is close to the average impact speed onto Helios, the small difference in the speed dependence can be neglected. There follows a relation between the particle density and the impact charge of particles at the penetration limit of the Helios film:

$$\rho_{pr} = \text{const.}\ Q^{-1.2} \qquad (4)$$

Therefore, it is possible to replace the pulse height scale by a density scale. This is shown in Fig. 3: Because all projectiles detected at the ecliptic sensor must perforate the film, the density scale means statistically a lower limit of the projectile density (upper diagram). Taking into account that the dust is concentrated towards the ecliptic the density scale is an upper limit for at least the surplus events counted at the south sensor (lower diagram).

Densities of micrometeoroids significantly lower than 1 g/cm^3 have been identified by the Helios experiment. Whether densities much lower than 0.1 g/cm^3 are still reliable, cannot be proved since they are extrapolated from the measurement.

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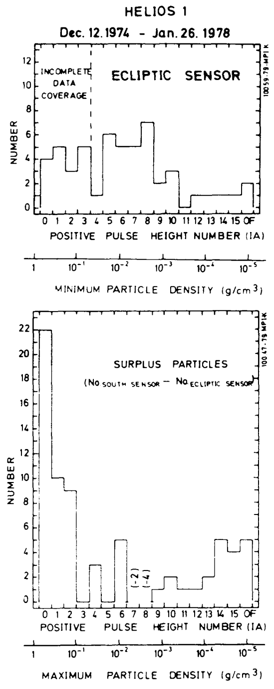

Figure 3: Replacement of the pulse-height-scale by a density scale

upper diagram: events detected by the ecliptic sensor

lower diagram: surplus particles detected by the south sensor

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DISCUSSION

Singer: I don't see how you can draw an absolute conclusion regarding the presence of low-density particles inasmuch as the two detectors may be observing two physically different populations and certainly two different velocity distributions.

Pailer: (1) We know (Grün, this volume) that both sensors can observe with equal sensitivity particles with orbit inclinations $i = 30^{\circ}$. Therefore, if one assumes an average inclination of 30° which seems reasonable from radio observations (Southworth and Sekanina 1973) and zodiacal light observations (Singer and Banderman 1967), then one expects more impacts to be seen by the ecliptic sensor than by the south sensor. (2) The penetration limit, T, depends on the particle mass, speed, and density while the released charge, Q, depends in a very similar way on the mass and speed but not on the density. The penetration limit, T, is equal to the Helios' film thickness and therefore the density is a function of the charge Q alone, almost independent of speed.

Zook: Following Singer's comment, I too worry about the uniqueness of your solution. I think your laboratory experiments show conclusively that meteoroids of low density will be discriminated against in the ecliptic sensor in the manner that you describe. However, are your laboratory calibrations so complete as to discriminate against very high-velocity (>50 km/s) small particles that may not register in the ecliptic sensor but do register in the south sensor?
Grün: The calibration covers speeds up to 20 km/s and densities down to 1 g/cm^3. Application of the penetration formula to speeds and densities exceeding these values are extrapolations from the laboratory data. But by allowing an uncertainty of a factor of 10 in the derived densities we feel that our conclusion that 30% of the "surplus" particles have densities <1 g/cm^3 is valid up to an impact speed of 50 km/s. If the average impact speed exceeds this, which is not very likely, the percentage of low-density particles may change but their existence cannot be ignored.

Hughes: What is the ductility value for aluminium?
Pailer: It depends on the particular alloy but is typically about 0.4.