ANALYSIS OF MICRONSIZED PARTICLES BY TIME OF FLIGHT SPECTROSCOPY OF THE IONS GENERATED BY HYPERVELOCITY IMPACTS

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ABSTRACT:

Onboard the ESA Halley-Fly-By-Mission GIOTTO is a Particulate Impact Analyzer, which uses the ions formed during impacts of cometary particles onto its target to measure their chemical composition. Mass resolution will be M/dM=200, the mass range is M= 1 to 110 amu. Mass spectra of more than 1000 particles will be obtained.

1. INTRODUCTION

After the impact of a particulate onto a solid target at a relative speed well above 1km/s, the following effects occur:
-- a crater is formed on the target
-- depending on the speed, the particulate is destroyed
-- secondary particles are emitted
-- a light flash occurs
-- a small plasma cloud is formed

The formation of a plasma has first been reported by Friichtenicht et al.(1963) and many instruments, measuring micrometeoroid impacts in space, were based on the detection of the impact plasma.

Mass analysis of the positive ions in this plasma, also reported by Friichtenicht et al. (1971), has first been introduced into a space instrument flown on HELIOS 1+2 and is described by Grün et al. (1977). The mass resolution of this instrument however was low (m/dm=15). Recently the Leybold-Heraeus-company has introduced an improved time-of-flight spectrometer into its LAMMA-instrument, and ´high´-resolution mass spectra can now be obtained in space experiments. Such an inmstrument has recently been proposed and accepted for the ESA fast-fly-by-misson GIOTTO to comet Halley by the following Invesitgator team: J. Kissel (PI), H. Fechtig, E. Grün, E. K. Jessberger, G. E. Morfill, H. J. Völk (all from Max Planck Inst. für Kernphysik Heidelberg), B.C. Clark (Marin Marietta, Denver USA), J.F. Friichtenicht (TRW, RedondoBeach USA), E.B. Igenbergs (TU München), J.A.M. McDonnell (Univ.of Kent, Canterbury GB), J. Rahe (Remeis Sternwarte, Bamberg), G.H. Schwehm (Ruhr Univ. Bochum), Z. Sekanina (JPL, Pasadena USA) and H.A. Zook (LBJ Space Center, Houston USA).

2. COMPOSITION MEASUREMENT

Figure 1 shows a schematic cross section of the PIA-sensor. Cometary particulates enter the sensor through a shutter (1) and impact onto the 5 cm^2 target (2) at a relative speed of 68 km/s and at an angle of 30^o off the target surface . The target has a relative potential of +1kV and consequently the positive ions of the impact plasma are accelerated through the acceleration-grid (3), which is at ground potential. Their total charge is detected at the monitor-grid (4). As they travel through the time of flight tubes (5+7) and the reflector (6), they separate according to their mass, as they have all the same energy. (Should they have a considerable thermal energy spread, the reflector is to provide first order energy focussing). Finally they arrive at the electron multiplier which serves as ion detector. The output signal of the multiplier is the time of flight spectrum of the positive ions of the impact plasma. It will be measured in the mass range 1 to 110 amu (corresponding to .04 ms) within a dynamic range of three decades. Calibration will be done at the Heidelberg Dust Accelerator.

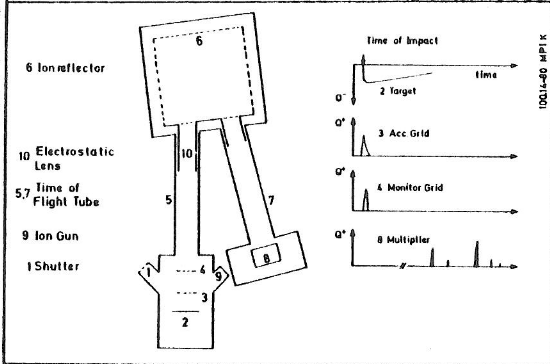


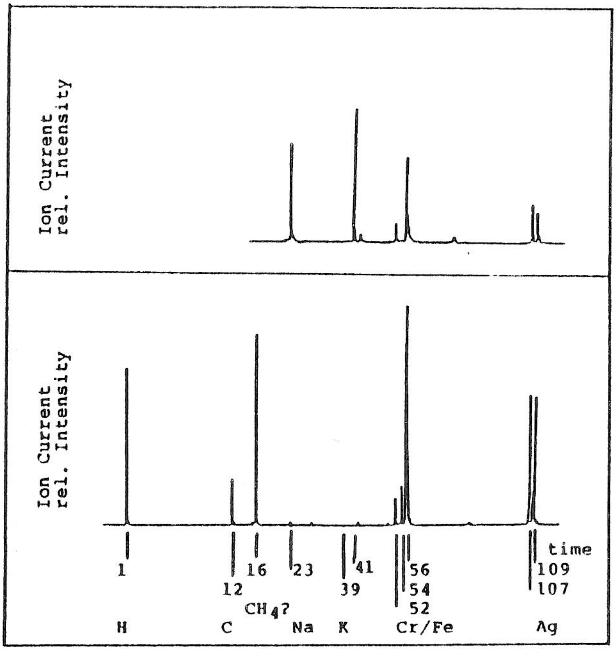
Figure 1: Sensor schematics and signal diagram.

3. COMPOSITION ANALYISIS

The composition of the plasma generated upon impact depends on many parameters, the phenomenon has first been treated theoretically by Raizer (1960). The degree of ionisation changes during the expansion and local thermodynamic equilibrium (LTE) holds until the energy exchange between the electron- and iongas is disturbed. (See Fechtig et al.(1978) and Drapatz and Michel (1974) for more details).

Dalmann et al. (1976) have discussed the variation of the impact plasma with impact speed. There are indications that ion-chemistry plays an important role during the expansion of the plasma, as e.g. Dalmann (1978) has shown that the composition of the impact plasma is greatly influenced by the presence of contamination of the target surface. He also showed that the influence of contaminants decreases at high impact speeds. Figure 2 shows an example for spectra of iron projectiles impacting on a silver target at speeds of 5 km/s and 39 km/s respectively. Whereas the low-speed-spectrum is dominated by sodium and potassium, typical surface contaminants, the high-speed-spectrum shows the dominance of the projectile drocarbons indicate organic layers on the projectile´s surface.

Figure 2: Impact ionisation spectra of Fe-particles onto a Ag-target.
Top: At 5 km/sec impact speed.
Bottom: At 39 km/sec impact speed.



Recently Braun (1980) has established relative sensitivities of such an instrument for various elements. During his measurements at the dust accelerator he varied both the target- and projectile materials. His values do reasonably well agree with those given by Sparrow (1976,1977) for ion yields in Secondary Ion Mass Spectroscopy. Their results are listed in table 1: With respect to other elements, so far not yet measured by impact ion spectroscopy, it is planned to use Sparrow´s yields as first order approximation, which is thought to match the quantitative abundances within a factor of 3.

Ref.:	Element Mg	Cr	Mn	Fe	Co	Ni	Cu	Mo	Pd	Ag
Braun	180	45	90	18 1)	32	13	16	3.8	5	12
Sparrow	130	30	47	18 1)	19	13	17	2	3	15

1) normalized for Fe, the standard dust projectiles

Table 1: Relative ion yields for Impact Ion Spectroscopy (Braun,1980) and Secondary Ion Mass Spectroscopy (Sparrow, 1976/1977).

The particulates, the instrument will encounter, will most likely resemble those particles, which Brownlee (1978) collected in the earth's atmosphere, or fragments thereof. These particles are agglomerates of very small grains (< 1 um) most of which are single crystals. The mean composition of these particles is believed to be similiar to that of Cl chondrites. In order to show which variations might be expected for a single grain analysis, elemental abundances of some sample minerals commonly found in meteorites are listed in table 2.

Mineral	Chemistry	Na	Mg	Al	Si	Ca	Ti	Mn	Fe	r
Cl-Chondrites:										
	Bulk composition in 10^7 atoms/1um particle of 1 g/cm^3 density:									
		13	240	19	220	17	.55	2.1	200	1
	Elemental abundances relative to Cl:									
Serpentine	$(Mg_6Si_4O_{10})(OH)_8$		2.6	.2	1.9	.01	.3	.3	.03	2
Olivine	$(Mg,Fe)\ SiO_4$		2.4		1.8	.07		1.6	.9	3
Anorthite	$CaAl_2Si_2O_8$	.3		11.3	2	12.6				2
Enstatite	$MgSiO_3$		2.5	.05	2.7	.2	.06	.1		4
Magnetite	Fe_3O_4			.07	.01				2.6	2
Spinel	$MgAl_2O_4$		1.4	20.4			20.8	.4	.04	5

Table 2: Top: Absolute concentrations of some elements in Cl-bulk material.
Bottom: Enhancement factors, relative to Cl, of some elements in selected minerals.
r: References: 1-Mason et al.,1977;2-Deer et al. 1966; 3-Fredriksson et al.,1967; 4-Reid et al.,1967; 5-Fuchs,1971

As seen from table 2, various minerals can be discriminated even with comparatively low accuracy in absolute composition measurement, as their relative composition differs grossly at least for some elements.

4. DATA SIGNIFICANCE

The nucleus, a body of a few kilometers in diameter, contains all the mass of a comet. It consists of ices, which make up its volatile component and of particulates (dust and rocks), the non-volatile component. The dust is believed to be loosely mixed with the ices so that the nucleus may be described as a 'dirty snowball' (Whipple, 1950). Circumstantial evidence suggests that the dust is particulate in structure, largely cemented by ices, very fragile and of low bulk density. Cometary nuclei appear to be highly non-homogeneous in terms of both, chemical composition and physical structure.
The composition of dust is largely unknown. Fragmentary information comes from infrared observations of a 10 micron emission feature, which is attributed to silicates (Ney,1974), from spectroscopic evidence on some metals far from the nucleus in comets with small perihelion distances, from spectra of mete-

ors which can be correlated to the producing comet (Millman, 1977).
As far as molecules are concerned it might be very interesting to look for very large molecules (or their fragments) in grains. Laboratory experments by Greenberg et al. (1979), irradiating NH_3- and CO- mixtures (which are expected to form ice mantels on interstellar grains) has produced molecular material with evaporation temperatures of 400 to 600 K and molecular weight possibly in the thousands. Assuming the mantels of interstellar grains to consist of such photochemically processed material, ti should be seen in cometary material rather than in meteoritic samples, where they might not have survived heating during formation.
It is the main objective of this experiment to clarify some of these questions.

5. SUMMARY

With both laboratory experiments and space instruments it has been demonstrated that mass analysis of the ions of the plasma formed by hypervelocity impacts reveals important information on the chemical nature of the projectile. The ESA mission GIOTTO to Halley with its high fly-by-velocity of 68 km/s provides a unique opportunity for the analysis of cometary dust particles with an impact analyzer. The mass resolution, which can be obtained in a space instrument is m/dm=200, the dynamic range within one spectrum 1000:1. The instrument allows elemental analysis to within a factor of 5, isotopic ratios can be measured to an accuracy of 30%. The data obtained on some 1000 cometary dust particles will reveal unique information on the composition of cometary particulates and and on the history of the formation of comets.

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