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The Giotto Particulate Impact Analyser

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Abstract

The Giotto Particulate Impact Analyser (PIA) will provide information on the composition of individual dust particles and the average composition and mass distribution of cometary matter released by Comet Halley. Knowledge of the material's composition and isotopic ratios (e.g. 7Li/6Li, 11B/10B, and 13C/12C) will significantly increase our understanding of the current status and the genesis of comets. The instrument is derived from the dust experiment flown onboard the Helios-1 and -2 satellites, but mass resolution has been improved to m/dm> 150 (PIA), which is sufficient to separate adjacent mass lines over the complete mass range of 1-110 u.

Variations in particle type or mean composition as a function of distance from the comet will yield information on the release mechanism. Impacts of particulates will be identified using the coincidence between the impact light flash and the signals from the positive ions formed during the impact process. The instrument will be sensitive to particles ranging in size from 3x 10**-16 to 5 x 10**-10 g (0.1-10 micro m diameter) with impact rates of up to 100 per second. Depending on the actual impact rate, data on some 1000-5000 cometary particles should be gathered by the Analyser.

The instrument has already been switched on and tested in orbit, on 13 October 1985, and is performing flawlessly.

1. Introduction

It is generally accepted that comets are so far best described by a 'dirty-snowball' model devised by Fred Whipple (1950). As such comets as Halley are thought to have remained largely unaltered since their formation in the solar system, the return of Comet P/Halley in 1986 provides a unique opportunity for in-situ studies of this unique material. One of the ten instruments carried by the Giotto spacecraft, launched on 2 July 1985, is the Particulate Impact Analyser (Figs. 1 and 2), which will provide information on the chemical composition of dust particles released by the comet.

Table 1 lists the team members associated with this investigation, their affiliations and responsibilities.

2. Scientific Objectives

The basic objective of the PIA instrument is in-situ measurement of the chemical and physical properties of cometary dust particles during the Giotto spacecraft's transit through the dust envelope of Comet Halley on the night of 13/14 March 1986. The chemical composition and masses of individual particles will be measured. Their impact rate, determined as a function of position relative to the comet's nucleus, will be used to establish the mass distribution and production characteristics of cometary dust.

Table 1. PlA Team Members

Member	Affiliation	Task
J. Kissel	MPI Kemphysik, Heidelberg	Principal Investigator
K. Buchler	MPI Kemphysik, Heidelberg	Experiment Calibration
H. Fechtig	MPI Kemphysik, Heidelberg	Experiment Development

E. Grun	MPI Kernphysik, Heidelberg	Data Link to Other Dust Experiments
E. K. Jessberger	MPI Kemphysik, Heidelberg	Link to Composition of Meteorites Expt.
H. J. Volk	MPI Kemphysik, Heidelberg	Relation of Composition to Formation of Comets
F.R. Krueger	MPI Consultant	Interpretation of Spectra
D.E. Brownlee	University of Washington, Seattle	Link to Particles from U2 Collections
B.C. Clark	Martin Marietta, Denver	Light Flash Detector, Link to Planetary Composition
K. Hornung	Technical College, Munich	Formation of Impact Ionization
E.B. Igenbergs	Technical University, Munich	Simulation of Large Particle Impacts
H. Kuczera	Technical University, Munich	Improvement of Simulation Methods
J.A.M. McDonnell	University of Canterbury	Link to DID, Special Design Tasks
G.M. Morfill	MPI Extraterr. Phys., Garching	Relation of Composition to Formation of Comets
J. Rahe	University of Bamberg	Link to IHW, and Optical Observations
G.H. Schwehm	ESTEC, Noordwijk	Correlation of Composition with Optical Properties
Z. Sekanina	JPL, Pasadena	Formation and Dynamics of Dust Tail
N.G. Utterback	JPL Consultant, Santa Barbara	Correlation with Laser Ionization (LIMS)
H.A. Zook	LBJ Space Center, Houston	Link of Cometary Dust to Interplanetary Dust

Figure 1. PIA sensor and electronics box prior to vibration testing (thermal paint not yet applied

In particular, the goals are to:

- determine the elemental abundance of individual particles and to ascertain whether there are distinct particle classes that differ from each other chemically
- investigate whether the elemental particle composition depends on the distance from the nucleus, and to look specifically for the effects of ice evaporation from particle surfaces
- gain insight into the molecular composition of the impacting particles, with
- emphasis on possible evidence of organic matter
  determine specific isotopic ratios, such as 6Li/7Li, 10B/11B and 12C/13C, and to try to establish the origin of the comet's particulate matter
- study the mass distribution function of impacting particles, derive the total dust production rate in the measured mass range, and compare the latter with theoretical models
- determine the extent of the dust envelope as a function of particle mass and analyze possible asymmetries in impact rate to model anisotropy effects in the dust's production

Figure 2. PIA sensor and electronics box mounted on their transport support in the same position as on the spacecraft

3. Scientific Background

3.1 Composition of cometary dust

The comet's nucleus, a body a few kilometres in diameter, contains all the comet's mass. It consists of ices, which make up the volatile components, and particulates, dust and rocks, which constitute the nonvolatile 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 the ices, very fragile and of low bulk density. Cometary nuclei appear to be highly inhomogeneous in terms of both chemical composition and physical structure. Many comets are believed to have their ice supplies dominated by H_2O, as predicted by Whipple (1950), although there is also evidence for the prevalence of more volatile substances in some comets.

The composition of the dust is largely unknown. Fragmentary information has been provided by infrared observations of a 1O micro m emission feature, which is attributed to silicates (Ney, 1974), from spectroscopic evidence on some metals (especially sodium and iron) far from the nucleus in comets with small perihelion distances, from spectra of meteors which can be correlated with the producing comet (Millman, 1977), and in a more qualitative fashion, also from high repulsive accelerations (due to the pressure of the solar light) on particles in some comet tails, indicative of the presence of (electrically) conducting materials. This is just one major question to be clarified by the PIA investigation.

It may also be possible to find larger (>>0.2 micro m diameter) particles dominated by individual minerals. One might, for instance, discover refractory-element-rich objects, which occur in some carbonaceous chondrites (notably Ca-Al-rich inclusions in allende). Their presence in the comet would indicate that such large refractory grains do indeed exist in interstellar space. Similarly, the presence of other minerals like magnetite or iron particles would suggest analogous conclusions. This would preclude extensive melting and recondensation of pre-cometary material, thus placing strong constraints on the processes leading to the formation of comets (Clayton, 1980). It is uncertain whether individual cometary particles are single crystals or aggregates of crystals. In the latter case one could imagine larger crystals surrounded by the very fine grained ’matrix’ material, particles similar to those collected by Brownlee (1978).

In either case, it will be possible with the PIA instrument to identify cosmochemically important minerals if they are present at all (Table 2).

3.2 Variations in composition

Every time a comet approaches the Sun, it loses part of its mass by evaporation of the ices, which in turn drag along the dust particles. The distribution of particles in the dust tail and the corresponding light-intensity distribution were shown by Finson & Probstein (1968) to contain astrophysically significant information on the production of dust with time, on the particle size distribution function, and on the particle ejection (terminal) velocities. However, this ingenious combined dynamical/ photometric-type method depends on certain assumptions regarding density, radius, radiation pressure susceptibility, on mass production rate and albedo. Knowledge of the chemical composition of the dust particles will therefore significantly improve our understanding of their dynamic behaviour.

An interesting consequence of the chemical heterogeneity of the nucleus is that less-volatile ices may be dragged away from its surface together with dust by the outgassing of more volatile ices. Delsemme & Wenger (1970) observed stripping of grains from a body of clathrate snow in their laboratory experiment. Moreover, the continuous spectrum of Comet 1960II was interpreted by Delsemme & Miller (1971) in terms of an ice-grain halo, the extent of which at heliocentric distances around 1 AU is small and recognizable by the steep rate of decrease of its radial brightness profile. The chemical heterogeneity of the nucleus mentioned above suggests that less-volatile ice grains may be expelled in the same way as the dust is ejected. The variation in the composition data acquired by the PIA instrument will yield a great deal of information on the ice grains, provided the spacecraft’s closest approach remains close to the nominal 500 km.

If the surface of a comet were perfectly homogeneous, the comet’s activity would be symmetrical with respect to the subsolar point. The nucleus’ rotation, however, and the existence of heterogeneities, produce unpredictable local variations in the production of both gas and dust, which, in turn, are responsible for the frequently observed deviations of the coma from symmetry and for the complicated coma structure, including such features as jets, fans, halos, secondary condensations, etc. Our investigation can clarify whether there are groups of particles of similar composition associated with those phenomena.

3.3 Light elements and isotopic data

Individual grains may show rather different isotopic compositions for several elements. Such differences exist in meteorites (isotopic anomalies) and again are most pronounced in allende. However, these ’anomalies’, as far as we know today, are most pronounced in the noble gases (>10%), which are not accessible to the PIA instrument, and in oxygen and magnesium (<10%), which will not be measurable either.

Averaging over many grains provides some interesting bulk properties in the abundances of some light elements. The bulk composition in carbonaceous chondrites and the Sun are closely similar. Still, there are notable exceptions. For example, lithium (Muller et al., 1975) is less abundant in the Sun by a factor 10**-2 than in C1, C2, and C2 carbonaceous chondrites (Nichiporuk & Moore, 1974), enstatite chondrites (Mason, 1971), pre-main sequence stars and young clusters (Zappala, 1972), as well as the stellar and interstellar media (Reeves & Meyer, 1978). Since stellar and interstellar abundances are about a factor of 2.2 below meteoritic ones, it will be interesting to study the trends in the cometary values. Similar enhancements between carbonaceous-chondrite abundances and solar versus stellar values do exist for beryllium (2,8) and boron (9,3). Meyer (1978) has discussed the idea that these Li, Be, B-enhancements in meteorites might be spallogene, due to energetic particle irradiation after formation of the Sun. If this is true, it could have affected comets only if they formed after the Sun. Even so, if comets originated far away from the meteorites, they would be less affected anyway, unless there were a particle source other than the Sun. Such arguments carry over to light-element isotopic ratios.

Table 2. Absolute concentrations of some elements in Cl-bulk material (above) and enhancement fact
relative to Cl, of some elements in selected minerals (below)

Mineral	Chemistry	Na	Mg	Al	Si	Ca	Ti	Mn	Fe	Reference
	Bulk composition in 10**7 atmos/1 micro m particle of 1 g/cm**3 density									
Cl-Chondrites		13	240	19	220	17	0.55	2.1	200	Mason &
	-Elemental abundances relative to Cl:									
Serpentine	(Mg6Si4O10) (OH)8	8	2.6	0.2	1.9	0.01	0.3	0.3	0.03	
Olivine	(Mg, Fe) SiO4		2.4		1.8	0.07		1.6	0.9	
Anorthite	CaAl2Si2O8	0.3		11.3	2	12.6				
Enstatite	MgSiO3		2.5	0.05	2.7	0.2	0.06	0.1		
Magnetite	Fe3O4			0.07	0.01				2.6	
Spinel	MgAl2O4		1.4	20.4			20.8	0.4	0.4	

Since the 11B/10B ratio on the Earth, Moon and meteorites is about 4.05 +/- 0.1 (Mason, 1971), it cannot be explained by beta-production through high-energy cosmic-ray spallation reaction within the lifetime of the Galaxy. This would only give 11B/10B=2.5. A postulated low energy (several 10 MeV/n) component would yield the ratio observed, but it is not obtainable by demodulation of the galactic cosmic-ray intensity observed near the Sun (e.g. Morfill et al., 1976). A cometary observation would lend support to (or exclude in the case of a small ratio) the relatively large-scale nature of such a low-energy component.

The 7Li/6Li ratio is observed to be about 12.5 (Krankowsky & Muller, 1976; Balsiger et al., 1968) in various meteoritic and terrestrial rocks. A spallation source from demodulated high-energy cosmic-rays could quantitatively produce the observed 6Li over the age of the Galaxy, but would only lead to 7Li/6Li=1.8. Various forms of low-energy cosmic-ray components would bring this ratio up to 6 (Reeves & Meyer, 1978). The role of extragalactic matter, containing 7Li produced in the ’Big Bang’ is also discussed. Since the 7Li abundance is strongly related to Big-Bang conditions, this measurement of the 7Li/6Li ratio outside the inner solar system would be very important.

The 12C/13C ratio in the gaseous coma of comets has been found to be > 100 (Vanysek & Rahe, 1978), somewhat larger than the terrestrial value and two to three times larger than the value found in interstellar clouds (e.g. Liszt, 1978). If this low interstellar-cloud value is due to low-temperature fractionations, as is probably true for the D/H enhancements there (Watson, 1977), a distinction between the 12C/13C ratios in the dust and gas of comets would shed some light on interstellar gas-grain chemistry.

3.4 Organic molecules

As far as molecules are concerned, it might be very interesting to look for very large molecules (or their fragments) in grains. Laboratory experiments by Greenberg and his associates (Greenberg, 1979), who irradiated NH3 and CO-mixtures (which are expected to form ice mantles on interstellar grains), have produced molecular material with evaporation temperatures of 400deg to 600deg K and molecular weights possibly in the thousands. Assuming that the mantles of interstellar grains consist of such photochemically processed material, it should be seen in cometary material rather than in meteoritic material, where they might not have survived heating during formation.

4. Experimental Approach

4.1 Sensor and electronics

A schematic of the PIA sensor is shown in Figure 3 and a block diagram in Figure 4.

After the impact of a particulate on a solid target with a relative velocity well above 1 km/s, the following effects occur:

- a crater is formed on the target
- the particulate is destroyed, to a degree depending upon the speed
- secondary particulates are emitted
- a light flash occurs
- neutrals, positive and negative ions, and electrons are released.

The phenomenon of impact charging was first reported by Friichtenicht & Slattery (1963), and many instruments for measuring micrometeoroid impacts in space have been based on this phenomenon.

The positive ions are detected at the target (TG), which has a potential of + 1 kV and at the acceleration grid (AC) at -2 kV; the impact light flash is detected by the photomultiplier (PM). These are the so-called ’front-end’ channels. As they are closest to the outside environment they may be sensitive to interference. The photomultiplier is therefore protected against stray light by the baffle and the diaphragm PIA 4 (Fig. 5). In addition each of the front-end channels has an r.m.s. noise meter attached to its output, which generates a reference voltage level serving as the level 0 threshold in such a way as to prevent noise pulses from becoming triggers of measuring cycles. They are blanked for short (10 micro s) pulses, so that they cannot exclude triggers by short-term electromagnetic interference and by ringing. Ringing produces an exceptionally high noise level, which is identified by noise status comparators. Their output is used to switch off these ’noisy channels’. A time window of 2 micro s is opened by the first active channel. The presence of impact-generated pulses in the other channels within this window is stored. The number of coincidences required for a signal to start a measuring cycle is set by the operating system.

Figure 3. Schematic cross-section of PIA
sensor and pulse shapes

Figure 4. PIA electronics block diagram

Figure 5. PIA sensor components
1. target unit with target foil
2. sensor head with entrance grid, shutter and
   flange for photomultiplier
3. sensor during mechanical assembly
4. ion reflector with electrodes
5. photomultiplier unit
6. straylight suppression baffle

A dynamic range of four decades is needed for 0.1 - 10 micro m particles. Such a large dynamic range could only be covered by switching the sensitivity of the amplifiers in two subranges covering a factor of 1000 each, separated by a factor of 100 (i.e. 1 - 1000, 100 - 10**5). log. input.

The outputs of the front-end channels are each monitored by three single-channel discriminators which are set at relative levels of X1, X10, X100 of the output voltage, irrespective of the sensitivity selections. The lowest possible limit of the experiment is 5X10**-14 Cb.

Having passed the acceleration grid, the ions are decelerated by the entrance grid of the first drift tube to 1 keV flight energy. Ion lenses within this drift tube improve the transmission of the instrument. After passing through this first drift tube, the ions enter the reflector section and are diverted into the second drift tube, after which they are detected with an electron multiplier. The reflector serves as a first-order energy-focussing device, compensating for the initial energies that ions might have from the formation process (up to some 70 eV).

Less exposed to the outside environment are the catcher (CA) channel, where electrons stemming from the impact of secondary particulates are measured, and the monitor (MO) channel measuring the induced charges of the positive ions at the first ion lens. Both channels are subject to simultaneous sensitivity switching by the same factor as the front-end channels. Their outputs are logarithmically compressed and digitized into one 6-bit word each, thus giving a resolution of +/-10%.

Before arriving at the multiplier, the ions have been separated in time according to their mass, forming a time-of-flight spectrum. The large dynamic range of five decades required a new approach. A. Glasmachers at the Institute for Electronic Design of the University of Bochum (Germany) solved the problem by exploiting the intrinsic amplification characteristics of the multiplier (i.e. each dynode amplifies by a constant factor, depending on the voltage applied). Using the signals of dynodes 5, 8, 11, 14, 17 and 20, converting them to a logarithmic output, and summing them gives a new fast logarithmic amplifier. The absolute gain depends on the gain of the multiplier, as shown in Figure 6.

To check the actual multiplier gain, an EPID (Electric Pulse Induced Desorption)-ion generator provides two mass lines of known intensity ratio. It is located a short distance from the multiplier and activated via the AHV-command. It was successfully operated in orbit on 13 October.

Figure 6. PIA logarithmic multiplier output signal curves (a) for low multiplier gain and (b) for high multiplier gain

Figure 7. PIA mass spectra of impinging dust particles during tests in all four data transmission modes. Lower spectrum is taken from multiplier preamplifier output to a transient recorder. Upper spectrum is reproduced from instrument telemetry data

Figure 8. Printouts of PIA EDF of mass spectra
Line number

1 Date / time / dust material

2 Sequence number / EDF length / test pulse counter / sensitivity (hi-lo)

3 Multiplier HV / target position / shutter position / file section / class of current event

4 Event number / spacecraft-time / spacecraft-sector / telemetry mode, spectrum mode

5 Ampl. photomultiplier / ampl. target / ampl.

acceleration grid / amp. monitor / ampl.
catcher / coincidences requested, actual

6 Impact rate / impact rate with spectra /
impact rate large events / class counters 1, 2,
3, 4 >= 5

7 Number of amplitudes / number of non-zero
amplitudes / maximum amplitude

8-end Spectrum data:
Mode 0: EDF-word number where content
changes from previous word / content
Modes 1-3: t**2-values / ampl. value, ’A’
designates amplitude samples

As masses 1 - 110 u arrive 4 micro s to 42.5 micro s after impact, a fast ADC and storage unit is needed. This event memory is power-strobed, 2 kx16-bit words long, and accepts the digitized amplitudes of mass lines and of the (time)**2 generator, a signal proportional to the ion mass. The mass spectra are measured in four different spectrum modes:

- 0-15 MHz mode: An amplitude sample of the MP output is taken every 66.66 ns and stored in the event memory
- 1 max/min mode: For each maximum appearing at the MP output, an amplitude sample and a sample of the t**2-generator is taken. A second set of samples is taken half a mass later (minimum sample). In addition, an amplitude sample is taken every 1.13 micro s, if no other maximum sampling occurred
- max/time mode: For each maximum in the spectrum, an amplitude/t**2 entry into the memory occurs. Additionally, an amplitude sample is taken every 1.13 micro s if no other sampling occurred
- 3 max. mode: Same as mode 2, but time samples taken only after 8.6 micro sec. Figure 7 shows mass spectra taken in these modes and Figure 8 the corresponding data printout.

4.2 Mechanisms

Even though the instrument can cope with rates as high as 500 s**-1, it needs a device that limits the impact range to the area from which ions can get into the sensor’s time-of-flight sections. The limiting aperture has an elliptical shape, and the impact area on the target is therefore circular with a diameter of 35 mm. This ’shutter’ can be varied from 5 cm**2 down to 1 mm**2, within 2.5 s. Figure 9 shows it in both positions.

Since surface contamination may contribute substantially to the impact-generated ions, it was mandatory to remove contaminants before mounting the target to the sensor. Several concepts were proposed and investigated and finally a design presented in one of the experiment definition studies (v. Hoerner, 1982) was selected. The target is a 10 micro m foil of Pt doped with 5% Ag, which is stored on one roll and moved during encounter at a speed of 0.6 mm/s. The roll is about 700 mm long and 55 mm wide.

Before mounting the target unit, the foil was transported onto the pickup roll and then ion etched on both sides as it was moved back onto the storage roll.

Figure 10 shows SIMS-spectra before etching, after etching, and after 20 days of storage under ambient sensor conditions.

Figure 9. PIA shutter device to limit the sensitive target area. Left: fully open position exhibiting 500 mm**2; Right: fully closed position exhibiting 1 mm**2

4.3 0perating system

Parameter setting

The PIA instrument is designed to measure the dust composition for a total of about 4 h, with the maximum impact rate occurring during 20 min centred around the time of closest approach, comparable to the command round-trip time from ground to spacecraft and return. This made it mandatory that the experiment be able to run autonomously. The hardware (based on a RCA 1802 microprocessor) and software providing this capability is called ’The Operating System’. The software, which resides in PROMs, evaluates instrument data and selects the parameters for instrument operation.

The basic status of the instrument is one of waiting for an impact to occur. To avoid being locked in this mode, a software flag is raised every second, after which the instrument updates its internal parameters; namely

(i) the impact rate for all events
(ii) the impact rate for large events, i.e. events where the X 100 threshold is exceeded in one of the front-end channels
(iii) the impact rate for events with mass spectra, i.e. events with a minimum of entries in the spectrum
(iv) the onboard time counter

It then:

(v) processes any command that has been received
(vi) sets the spectrum mode
(vii) enables trigger channels
(viii) sets the number of coincidences required
(ix) adjusts the sensitivity setting
(x) sets the multiplier high voltage
(xi) adjusts the shutter position
(xii) effects target movement if needed.

Figure 10. PIA target cleanliness
Top - Prior to ion sputtering
Centre - After cleaning
Bottom - After 20 d of storage under dry nitrogen

When the data of an individual event are evaluated, formatted, characterized and prepared for telemetry transmission, some values sampled during this process are used for control purposes:

- IR: The actual ’Impact Rate’, i.e. the number of events occurring per second
- IRL: Number of events per second, larger than its X 100 threshold
- IR4: Number of events per second that also show a spectrum corresponding to a class-4 to -7 event
- TMR: Number of EDFs transmitted per second

Moreover, the operating system conducts regular testing of the instrument, whereby all analogue channels are stimulated with test pulses of different defined amplitudes and with proper timing.

All parameters are preset whenever the experiment is switched on. When switch-on occurs for the first time, initial values stored in the PROMs are taken. During normal experiment operation, actual values are continuously written to a section of the RAM, which is kept powered whenever the spacecraft is on. For a subsequent switch on, the values from this powered memory are taken, thereby ensuring that the experiment comes on in the state it was in when turned off.

The same process occurs on an interrupt caused by the ’watchdog’ function of the instrument, i.e. if a hardware timer is not reset by the operating system at least once per 7.7 s.

Setting the coincidence request

The main criterion for real impacts, aside from the existence of a mass spectrum, of course, is that the front-end signals are coincident. As small particles may not be represented in all three channels, no coincidence is required to trigger an event under normal conditions. The coincidence request starts to come into effect if the 'IR4' > 10/s and 'IR' > 2xIR4. One additional coincidence is then requested. It is updated every second.

Disabling trigger channels

The front-end channels may be triggered more often than the whole system can tolerate. In this case, the noise detection system raises the trigger level. Should this value reach more than 3.2 V, the offending channel is precluded from triggering. It is enabled again if the trigger level drops below the above value. The number of active channels is also considered for coincidence requests. Should all three front-end channels need to be switched off, the instrument is automatically set to the low-sensitivity mode, and all front-end channels are enabled again.

Setting the sensitivity

The instrument can be set into a 'HI' (high) and 'LO' (low) sensitivity mode, whereby the channels AC/PM/TG/CA and MO are affected. It only makes sense to select LO sensitivity if there are enough events to fill the telemetry capacity. The following criterion has been chosen for the switchover from HI to L0:

IRL (large events) > [TMR (EDF rate)) + 3

In addition, the shutter is caused to open, all channels are enabled, and no coincidences required. Once in the LO state, the instrument remains there for 4 s and then unconditionally returns to the HI setting.

Setting the spectrum mode

The different modes for recording the mass spectrum have been described above. Mode 0 is used exclusively with Data File Section 13 for every 26th event. Selection of the other modes depends on the ratio of 'IR4' and 'TMR'. The mode number is increased by 1 whenever IR4 >/= 2 xTMR, or 1R4> 128. It is reduced again if IR4<2xTMR. Changes are effected after 4 s have elapsed.

Shutter operation

The shutter is a device in front of the target that controls the area that can be hit by the incoming particles. The aperture is set under microprocessor control by a stepper motor. Two switches are used to identify the 'open' (500 mm**2) and 'small' (52.4 mm**2) positions. For technical reasons (vibration load on the switches), the 'zero' position is somewhat smaller (457 mm**2). The smallest aperture (ca. 1 mm**2) is reached after 71 motor steps.

After any switch-on, the shutter opens to the 'zero' position. During experiment operation, the aperture is controlled by the IR4 (events with spectra) using the following criteria:

IR4> 90:   close by 3 increments IR4 <60: open by 3 decrements
IR4> 180: close by 6 increments IR4 <30: open by 6 decrements
IR4> 254: close by 9 increments IR4 <15: open by 9 decrements

-a decrement/increment being three motor steps in the range of small shutter apertures, and 10 motor steps outside this range.

Target movement

As mentioned above, the quality of the mass spectra largely depends on the cleanliness of the target. Movement of the target is effected in two ways: by telecommand and automatically. A telecommand will be used prior to encounter to remove the target area that has been exposed to the environment during tests and launch. During the actual flyby, the target starts moving whenever IR4> 60 and stops when IR<30.

As only one motor should move at any time, the shutter has been given priority over the target.

Setting the multiplier high voltage

The high voltage of the multiplier controls both the sensitivity and the dynamic range for the mass spectrum. There are three possible states for it:

- off, i.e. no high voltage at all
- low, i.e. a value of 200+nX39.7 V, where n denotes a selectable number of voltage increments, ranging from 0 to 63
  normal, i.e. a value of 2000+nX39.7 V, giving actual values between 2000 and 4500 V.

The value for the high voltage is set exclusively by telecommand. Only during execution of a stimulus routine (CMD AVH) is it raised five times by 3 steps, i.e. by some 600 V. In order not to lose the correct value, the register controlling the HV converter is updated each second from the main memory.

4.4 Telecommanding the PIA

A number of telecommands have been defined for the remote control of the instrument. They are defined in 16-bit serial words of the following structure:

Bit	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
	P	A	A	A	A	C	C	C	D	D	D	D	D	D	D	D

where

P = parity bit to be set for even parity of the command word
A = PIA address, binary: 1011
C = command type, binary:
  000 = NOP0 No Operation (for test purposes)
  001 = NOP1 No Operation (for test purposes)
  010 = ESR Execute System Reset by Hardware Reset
  011 = EIT Execute Inflight Test Sequence
  100 = MSH Move Shutter
  101 = MTG Move Target
  110 = SHV Set Multiplier High Voltage
  111 = AHV Adjust Multiplier High Voltage
D = 8 bits of data, defining in detail the action to be executed upon receipt of the command.

The instrument system considers only commands that have the correct parity P and address A. For correct commands, the type C defines an address in the memory and D the data to be written to this address. The command is then executed after the next event has been processed, or after 1 s at the latest.

4.5 The data-handling system

The data-handling system collects all values measured by the Analyser’s various elements. The number of coincidences is read and the number of entries in the event memory and in the mass windows are checked and the class of the event is established.

Events are classified as follows:

1. events that have one front-end signal only
2. events that have one coincidence between two front-end channels, but no spectrum
3. events that have all front-end coincidences, but no spectrum
4. events that have a minimum of 52/46/10 entries in the spectrum for modes 1/2/3, respectively
5. events that have a minimum of 54/48/12, but not more than 228/148/140 entries in the spectrum, and in addition a minimum of 26/21/6 entries in the mass window(6-58u)
6. class-5 events that have, in addition, a minimum of 2 entries of at least 1/5th full scale between mass 5 and 8
7. class-5 events that have a minimum of 34/27/12 entries in the mass window, but no more than 93/49/46
8. events of the statistical sample

9. test pulses from the test-pulse sequence
10. events from the AHV routine, i.e. spectra of the multiplier stimulus, the emitter
0. events that have already been transferred to telemetry.

After event classification the memory is checked for empty sections or those holding lower class data. If feasible, the data of the current event are transferred to the main memory, and the ’experiment data frame’ header is added. The system then goes back into the loop, waiting for the next event to occur. Table 3 shows the layout of the experiment data frame.

Table 3. PlA experiment data frame

Word no.	(8 bits each)	Contents	Remarks
0	ID Field MSB	Experiment identifier	
1	ID Field ISB	Experiment identifier	
2	EDF Length MSB	Length of current EDF in bytes and data file section (high 4 bits)	
3	EDF Length LSB	Length of current EDF	
4	Shutter Status	Shutter position from pot.	
5	Target Status	Target position in motor steps	
6	HV Status	MM 1 HV control word	
7	Operation Status	Sens.- and TM.-status	Pattern A
8	EDL Status	EDL configuration word	Pattern B
9	Impact Rate	Impacts/s all events	
10	Impact Rate L	Impacts/s large events	
11	Impact Rate S	Impacts/s events with spectrum	
12	Event Counter 1	No coinc. events	
13	Event Counter 2	Dual coinc. events	
14	Class Counter 3	Triple coinc. events	
15	Class Counter 4	Events with spectrum	
16	Class Counter 5	Events class >= 5	
17	Event Number High	Number of current event, MSB	
18	Event Number Low	Number of current event, LSB	
19	Time High	Impact time, MSB	
20	Time Low	Impact time, LSB	
21	Sector	Solar aspect at impact	
22	Lightflash	Level of PM + IFT ID + Event class	Pattern C
23	Target + ACC.	Levels of TG and AC	Pattern D
24	Monitor	Amplitude monitor	
25	Catcher	Amplitude catcher	
26	IFT Type	IFT sequence counter	
27	Sequence No. MSB	Sequential count of EDFs from	
28	Sequence No. LSB	the experiment	
29	Time *	Mass spectrum	
30	Amplitude*	Mass spectrum	
		Mass spectrum	
		Mass spectrum	
E-1	Time *	Mass spectrum	
E	Amplitude *	Mass spectrum	

Bit	Pattern A	Pattern B	Pattern C	Pattern D
LSB	TG Sens. 1 = HI		PM Level 0	TG Level 0
LSB +1	AC Sens. 1 = HI	Sp. mode 0-3	PM Level 1	TG Level 1
LSB +2	PM Sens. 1 = HI	Coinc. 3 of 3	PM Level 2	TG Level 2
LSB +3	CA Sens. 1 = HI	Coinc. 2 of 3	IFT ID 1 =IFT	AC Level 0
LSB +4	MO Sens. 1 = HI	Coinc. 1 of 3	LSB { Class	AC Level 1

LSB +5	TM OBDH code	PM 1	= ON	LSB +1	{ of cur-	AC Level 2
LSB +6	TM OBDH code	TG 1	= ON	LSB +2	{ rent	Unused
MSB	TM OBDH code	AC 1	= ON	LSB +3	{ event	Unused

- * No. of samples and EDF length changes with actual number of peaks in mass spectrum

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