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THE "VEGA" PROBE INSTRUMENT PACKAGE FOR MEASURING CHARGED PARTICLES WITH ENERGIES LESS THAN 25 keV

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ABSTRACT

The VEGA probe instrument package is designed to measure particles with energies less than 25 keV. Instruments for detecting ions in the 50 eV to 25 keV range and electrons in the 3 eV to 3.5 keV range will be carried on board the VEGA probe. They include two ion spectrometers - one oriented to the Sun to determine the energy spectrum of ions up to 35 keV and the second oriented along the spacecraft-comet relative velocity vector - to measure both energy and mass spectra of cometary ions, for masses between 1 and 100 a.m.u. In addition two integral plasma detectors (plane retarding-potential analysers) will be oriented in the same way as the ion energy spectrometers. The electron energy spectrometer will be oriented perpendicularly to the Sun-spacecraft direction. In the vicinity of the comet one complete set of electron and ion spectra will be measured every second.

1. INTRODUCTION

The flight of the Venera-Halley (VEGA) spacecraft to Halley's Comet in March 1986 will make it possible to carry out some "in-situ" measurements near this comet, i.e. local plasma characteristics can be studied along the spacecraft trajectory in a manner that cannot be reproduced using remote measurements of any electromagnetic waves radiated by the comet. This paper briefly describes the measurements of the "cold" particle (energies less than 25 keV) plasma that will be obtained from the VEGA spacecraft. The experiments were designed to answer the following main questions:

1. How do solar wind parameters change while the spacecraft approaches the comet?

2. Does a near-cometary shock exist in the solar wind and if it exists, where is it located and how do the solar wind plasma parameters change across the shock front?

3. Where is the "contact surface" (the cometary ionosphere boundary) located and what are the number-density and the chemical composition of ions in the cometary ionosphere?

4. What is the chemical composition of ions produced by photoionization of cometary neutral particles outside the contact discontinuity and even outside the bow shock and picked up by solar wind?

There is no commonly accepted opinion about the existence of near cometary shock nor on the location of the contact surface. Currently, data on the cometary ionosphere are virtually nonexistent.

We still do not know exactly what will be the minimum distance from the cometary nucleus at which the measurements will be carried out. Thus, we have developed the instruments in such a way as to obtain maximum sensitivity and to cover the maximum dynamic range of the parameters being measured. This makes it possible to study all regions of the near-cometary environment independently of model assumptions. As a consequence of this and weight limitations it was desirable to design rather simple lightweight instruments for charged particle measurements. As the main emphasis of the VEGA program was put on remote sensing instruments (Sagdeev et al. [1]), there was only a very limited weight available for plasma experiments.

2. SENSORS

The Plasmag-1 instrument package includes the following detectors:

- an electrostatic energy analyser, pointed towards the Sun, for ions with energies within the range from 50 eV to 25 keV;
- an electrostatic energy analyser oriented along the spacecraft-comet relative velocity vector for ions with energies within the range from 15 eV to 3.5 keV and masses within the range from 1 to 100 a.u.; this mass and energy range will permit the measurement of cometary ions;
- an electrostatic energy analyser oriented normal to the sunward direction for electrons within energies ranging from 3 to 1000 eV;
- two integral plane multigrid analysers (RPA): one is oriented along a vector of the spacecraft-comet relative velocity vector and the other is oriented towards the Sun. The first one can be used in different modes of operation (which are described further). The second one is designed to measure the total ion flux of the solar wind as well as its fluctuations.

3. SENSITIVITY AND DYNAMIC RANGE

The ion electrostatic analyser oriented along the spacecraft velocity vector relative to the comet will have a minimum measurable number-density of 10^{-3} cm^{-3} and a maximum of 10^{5} cm^{-3}. (The dynamic range is therefore 10^{8}.) As one can see in the cited paper (Gringauz et al. [2]) such a sensitivity should be sufficient to detect photoions of cometary origin picked up by the solar wind at distances up to $\sim 10^{7}$ km from the cometary nucleus; on the other hand, 10^{5} cm^{-3} is the probable number-density of ions deep within the ionosphere according to current theoretical models of the near-cometary region.

The ion temperature of the near-cometary plasma according to models is estimated as 10^{3} to 10^{4} K, that is, $E = 0.1$ to 1.0 eV, which is so much less than the energy of ions adequate for the directional velocity relative to the spacecraft (for hydrogen ions E = 32 eV). Hence, the mass distribution of the near-cometary plasma inside the contact surface can be measured with an energy spectrometer that acts as a ram-mass-spectrometer with the energy resolution of 4 to 5% corresponding to mass resolution $\frac{m}{\Delta m}$ about 20 to 25. The maximum energy E_m = 3500 eV and the mass range is from 1 to 100 a.u. The time for measuring 120 energy intervals of one energy mass spectrum is 1 sec, which corresponds to a spatial resolution of 80 km. Since the energy range of this ion energy analyser is from 15 to 3500 eV and the ion velocity relative to the spacecraft is 80 $\frac{km}{s}$ the ion mass can be determined from 1 to 100 a.u. (Proton energy is 32 eV.)

The energy analyser oriented to the Sun has an energy range from 50 eV to 25 keV.

Since the spacecraft is three-axis stabilized, and since the angle of arrival of solar wind ions varies, the angle of acceptance of the analyser oriented to the Sun is broadened to $\pm 25^{\circ}$ by the use of an electrostatic lens. This instrument together with the TÜNDE-instrument (the lower threshold of energy of which is 20 keV - see Somogyi et al. [3]) makes is possible to record ions arriving from the Sun with energies ranging from 50 eV to 500,000 eV and more. The knowledge of solar wind velocity gives one the possibility to estimate the masses of picked up ions of cometary origin registered by TÜNDE. The instrument sensitivity is from 10^4 to 10^8 cm^{-2} sec^{-1}.

The energy analyser of electrons is oriented in a direction normal to the sunward direction. This is both for the measurement of solar wind electrons ahead of and behind the near-cometary shock and the measurement of energetic electrons inside the cometary ionosphere since this might clarify the situation with regard to anomalous ionization of cometary neutrals. The dynamic range of electron energy analysers is 10^4-10^{11} cm^{-3} $ster^{-1}$ s^{-1}.

The duration of the energy spectra measurements is 1 sec for each of the three spectrometers mentioned above.

Two plane integral multi-electrode plasma detectors of RPA type record the integral fluxes of particles without their energy analysis. One of them is intended for recording the ion fluxes and is oriented towards the Sun; it allows the ion flux to be measured 8 times per second. The second detector is oriented along the spacecraft velocity vector relative to the comet; it can operate in four different modes depending on the voltages applied to its electrodes and this should make it possible to measure both cometary ion fluxes and secondary electron fluxes emitted from the collector as a consequence of the input of neutral particles and dust. The characteristics of the device are summarized in Table 1.

4. DESCRIPTION

The same type of inflight calibration is used for all the energy spectrometers in order to check the stability of the channeltron characteristics. It is easier to describe the instrument starting with the electron energy spectrometer.

4.1 Electron energy spectrometer

Fig. 1 is a schematic diagram of the electron analyser. The instrument includes a 120 degree cylindrical deflecting system to which each second a series of 30 analyser potential steps is fed that are logarithmically spaced. The input area of the analyser is 0.1 cm^2, the mean radius of curvature is 45 mm, and the energy gain is

$$E/eV = \frac{1}{2 \ln (R_2/R_1)} = 10 .$$

R_1 and R_2 are the radii of the internal and external deflecting plates. The angular and energy resolution calculated using these are $\pm 3.5^o$ and ±7% respectively, and the energy-geometrical factor is $2x10^{-5}$ E cm^2 ster keV.

The instrument aperture is oriented perpendicular to the Sun-spacecraft line. This protects the spectrometer against both solar UV-radiation and dust and neutral particles coming from the comet.

To determine the degree of degradation of the channeltrons, a special calibrating device is used; it is a separate cylindrical analyser using the same channeltron whose particle source is a

Table 1

Parameters	Integral Detectors		Energy spectrometers		
	to the Sun	to $\vec{V}_{SC-com}$	ions along to $\vec{V}_{SC-com}$	ions pointed to the Sun	electrons
Aperture	1.3 cm^2	1 cm^2	0.1 cm^2	0.1 cm^2	0.1 cm^2
Angle of acceptance	±45°	±8°	±6°	±35°	±5°
Energy range and resolution	>25 eV >3500 eV >0 eV	>25 eV >3500 eV >0 eV	15 ÷ 3500 eV $\Delta E/E = 4\%$	50 ÷ 2.5×10^4 eV $\Delta E/E = 4\%$	3 ÷ 10^4 eV $\Delta E/E = 5\%$
Masses range and resolution			1-100 a.u. $M/\Delta M = 25$		
Dynamic range (T - time of I spectrum measurement)	10^7-10^{10} $cm^{-2}s^{-1}$	4-4×10^5 cm^{-3}	10^{-3}-10^4 (T=1 s) 10^{-5}-10^4 (T=150 s) cm^{-3}	10^4-10^8 (T=1 s) 10^2-10^8 (T=150 s) $cm^{-2}s^{-1}$	10^5-10^{11} (T=1 s) 10^3-10^{11} (T=150 s) $cm^{-2}ster^{-1}s^{-1}$

tritium isotope with a decay period of 9 years providing electrons with energies within 15 keV. The calibration of the channeltron is performed periodically once a day, it is switched on by a command. To provide a large dynamic range of measurements (it is especially required if the spacecraft approaches close to the comet nucleus where the plasma density is expected to be high (~10^5 cm^{-3})), an additional regime of measurements is introduced whose sensitivity is reduced by two orders of magnitude.

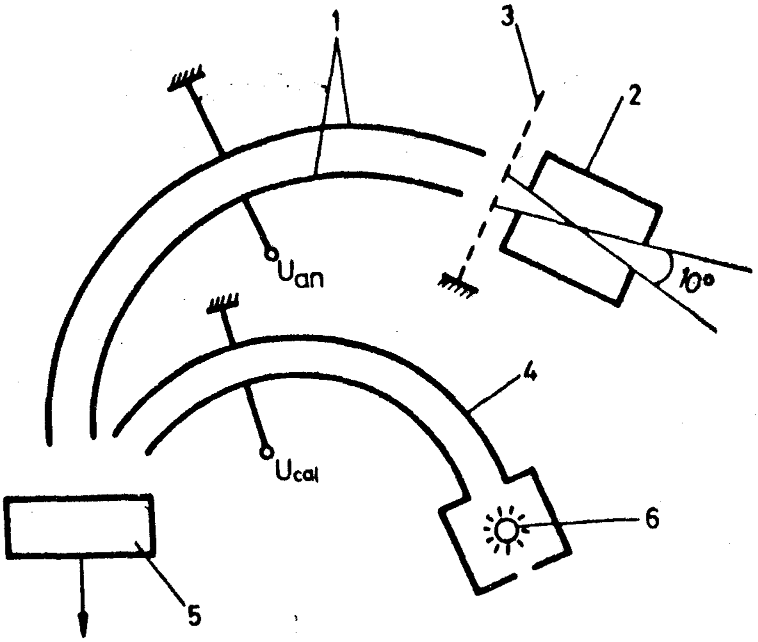

Fig. 1. Electrostatic particle energy analyser

1 - deflecting plates for energy analysis,
2 - electrostatic lenses,
3 - grid,
4 - deflecting plates for calibration,
5 - channeltron,
6 - electron source for calibration.

This mode is performed for 0.5 sec every 4 seconds but only for measurement of electrons with energies up to 100 eV.

4.2 Ion spectrometers

As mentioned earlier, to measure the ion components of the solar wind and cometary plasma, two similar, simultaneously operating spectrometers (electrostatic analysers) are used. Due to the limitations mentioned above the three dimensional ion distribution function cannot be obtained only, the energy distributions can be measured. To avoid the uncertainties associated with aberration angle and variations of ion angle of arrival, the angle of acceptance of the solar spectrometer was essentially extended (the same to a lesser extent was done with the cometary ion spectrometer).

The peculiarity of the cold plasma energy spectrometer is its operation under the influence of intensive flow of neutral particles in the comet atmosphere which may exceed the cometary ion flow by several orders of magnitude and the flow of dust particles. Neutrals interacting with the spacecraft in general and with this instrument in particular will form secondary electrons and dust particles will produce a plasma cloud surrounding the spacecraft. The instrument should be insensitive to these effects.

The necessity for high sensitivity of the spectrometers and for the protection of its detector from UV-radiation and, in the case of the cometary ion spectrometer, from neutrals and dust particles, forced us to use electrostatic analysers. As high resolution $\Delta E/E$ leads inevitably to a small angular aperture, the wide angle of acceptance and high energy resolution can be obtained simultaneously only by using an electrostatic analyser with an electrostatic lens near the aperture to widen the angle of acceptance of the aperture.

A schematic of the solar wind and cometary ion spectrometers is given in *Fig. 2*. Each spectrometer is a hemispherical electrostatic analyser with a quadrupole electrostatic lens mounted at its entrance port. The average radius of the curvature is $R = 45$ mm, the gap between electrodes is $\Delta R = 2.5$ mm. Parameters of the analyser and the electrostatic lens are selected so that their e/eV values coincide and equal 7. One peculiarity of the spherical analyser is its 'knife' edge angular aperture with a small input window. It makes it possible to control the lens operation so that the expansion of the angle of acceptance is different for ions coming from different directions - in one plane 7 - and in the perpendicular one 0.6-0.8. Therefore the general value of the decrease of the instrument's senstivity to the directed flow of particles associated with the expansion of its angular aperture amounts to a value ~5. The energy analysis of the ion flux is performed by applying a series of positive voltages to the external electrode of the analyzer. In the fastest mode (near the comet) 30 steps of voltages are applied to the solar wind spectrometer (within 1 sec and to the cold plasma spectrometer 120 steps within 1 sec.

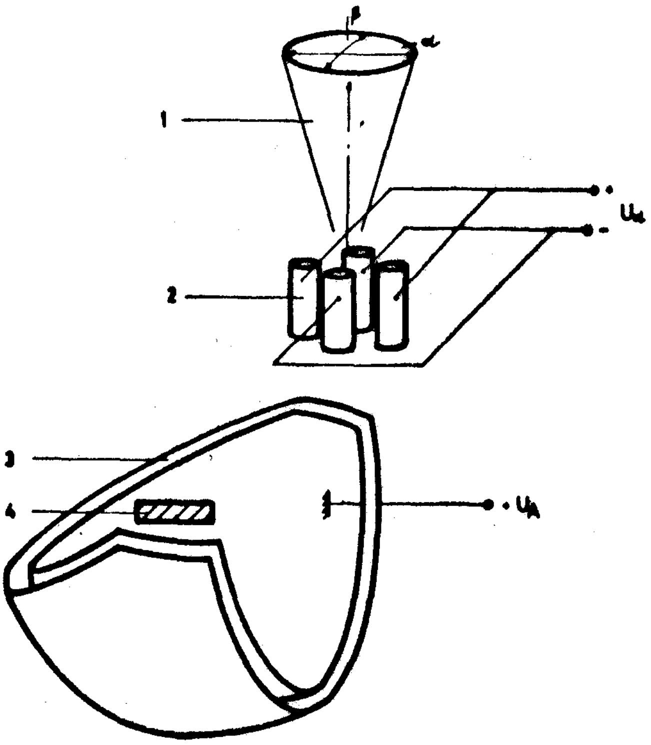

Fig. 2. Solar wind ion spectrometer

1 - acceptance angle,
2 - quadrupole lens,
3 - analyzing spherical system,
4 - channeltron.

In the latter case, the 120 steps cover the whole energy range from 15 to 3500 eV without any gap. Thus, the measurements of any mass in the range from 1 to 100 a.u. are guaranteed. For the solar wind spectrometer 30 steps are distributed logarithmically over the energy range 50 eV - 25 keV.

However, in the range below 5 keV near the peak of the solar wind ion energy distribution, more steps are applied. *Fig. 3* gives calculational angular characteristics for the 'adjusted' analyser with the lens switched on and off for particle trajectories in two mutually perpendicular planes as an example of the operation of the combination of the electrostatic lens and the analyser. Here it is shown what happens when in one plane the angular characteristic shrinks from 40° to 30° while in the other one it expands from 4° to 30°. The spectrometer's angular aperture thus represents the average between a circle and square with a diagonal of 30°. Each spectrometer is equipped with a calibration

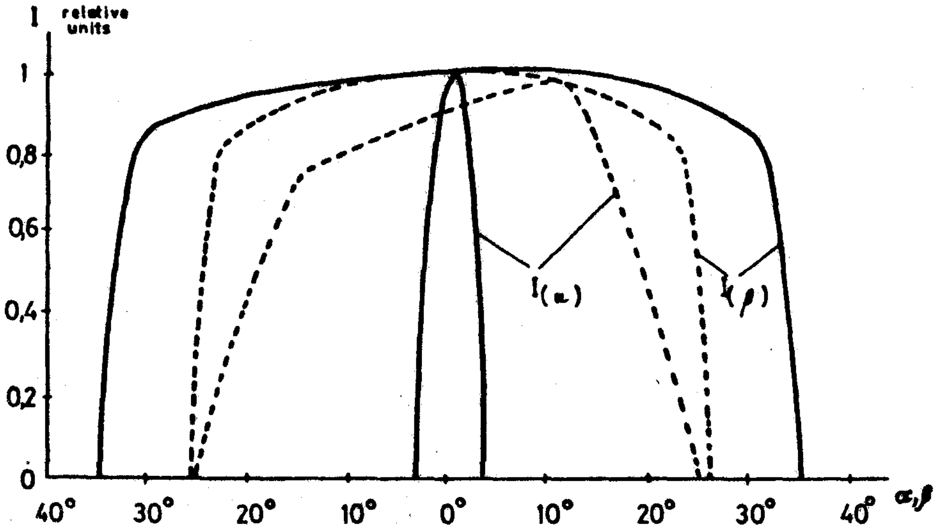

Fig. 3

Angles of acceptance of ion analyser $I_{(\alpha)}$ *and* $I_{(\beta)}$
Solid lines-electrostatic lens switched off; dashed lines-switched on.

device with a tritium electron source. The calibration time schedule is similar to that of the electron spectrometer. In order to avoid the direct interaction of cometary neutrals and dust particles with the analyser there is a special trap which is aligned along the spacecraft-comet relative velocity vector so that secondary electrons and plasma created by these neutrals and dust particles cannot get into the deflecting system of the analyser (*Fig. 4*). There are no grounds to expect high flows of

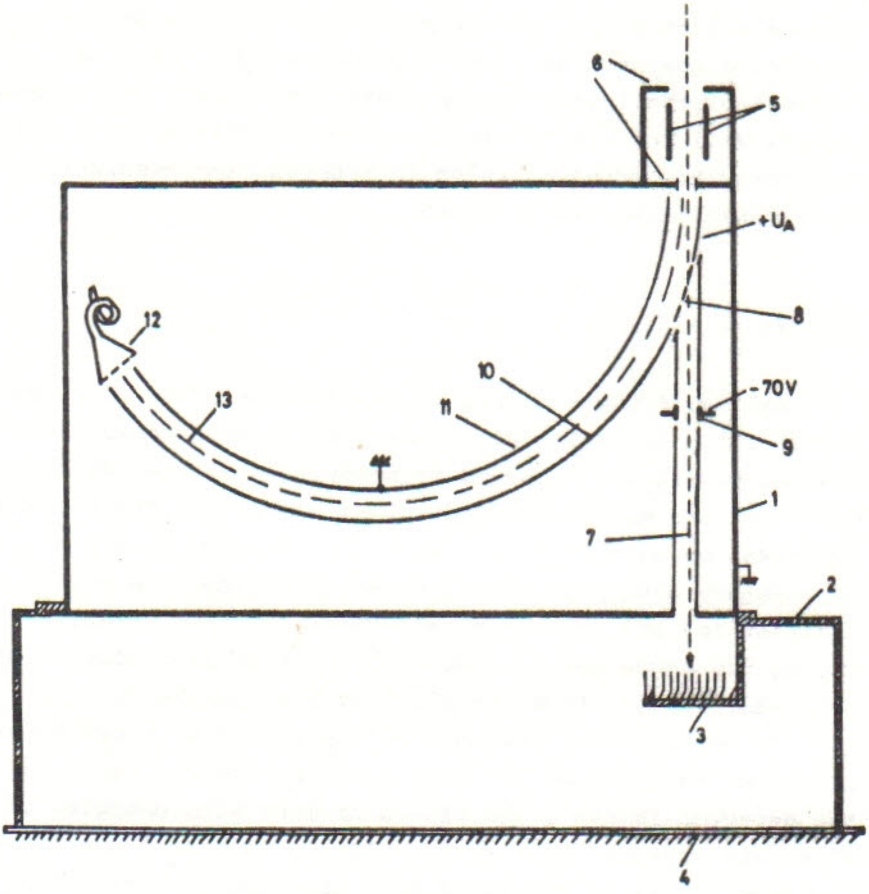

Fig. 4. Ion analyser

1 - analyser housing
2 - electronics housing
3 - neutral trap
4 - space probe
5 - electrostatic lense
6 - aperture
7,8 - neutral path
9 - secondary electron checking
10,11 - deflecting plates
12 - channeltron
13 - ion path

ions in the direction from the Sun both in the solar wind and in the comet magnetosphere, therefore the solar wind spectrometer has a dynamic range of 10^5 (5×10^4-5×10^9 cm^{-2} $ster^{-1}$).

In the cometary ion spectrometer a device is included to decrease the sensitivity by 3 orders; it is switched on periodically for 1 sec (one full spectrum measurement) every 4 seconds. Even if not optimal from the point of view of performance, we regarded this mode of operation to be more reliable than automatic switching if the ion fluxes increase. At the same time it can also be expected that during high sensitivity modes (3 cycles) only for a few intense peaks (possibly, H_2O^+, CO_2^+) will the readings of the instrument be distorted; in any case correct spectra will be obtained in the (low sensitivity) 4th cycle. Therefore this mainly results in reduced time resolution if such for intense peaks really appear.

4.3 Integral plasma detectors

In *Fig. 5* the integral plasma detectors are shown schematically: (a) - for solar wind ions; (b) - for cometary ions (or for charged particles, produced by neutrals and cometary dust). These detectors are multi-electrode plane analysers. Their designs are different because analyser (b) has to survive in the direct flux of cometary dust particles. The angle between the normal to analyser (a) and the spacecraft-comet relative velocity vector during the encounter is about 60°, thus it is easier to protect this analyzer (a) from the striking dust particles.

In detector (a) protection is provided by short honeycombs installed in front of the aperture; the angle of acceptance of the detector is ±45°, the fluxes of ions with energies of about 20 eV are expected to vary from 10^7 to 10^{10} cm^{-2} sec^{-1} can be recorded (so it is protected from the ions of surrounding spacecraft plasma, produced in the process of interactions of dust particles with the spacecraft: ions are retarded by the positive potential of grid 3, electrons by the negative potential of grid 1). During encounter, 8 collector current measurements per second will be made which will enable one to observe slow fluctuations

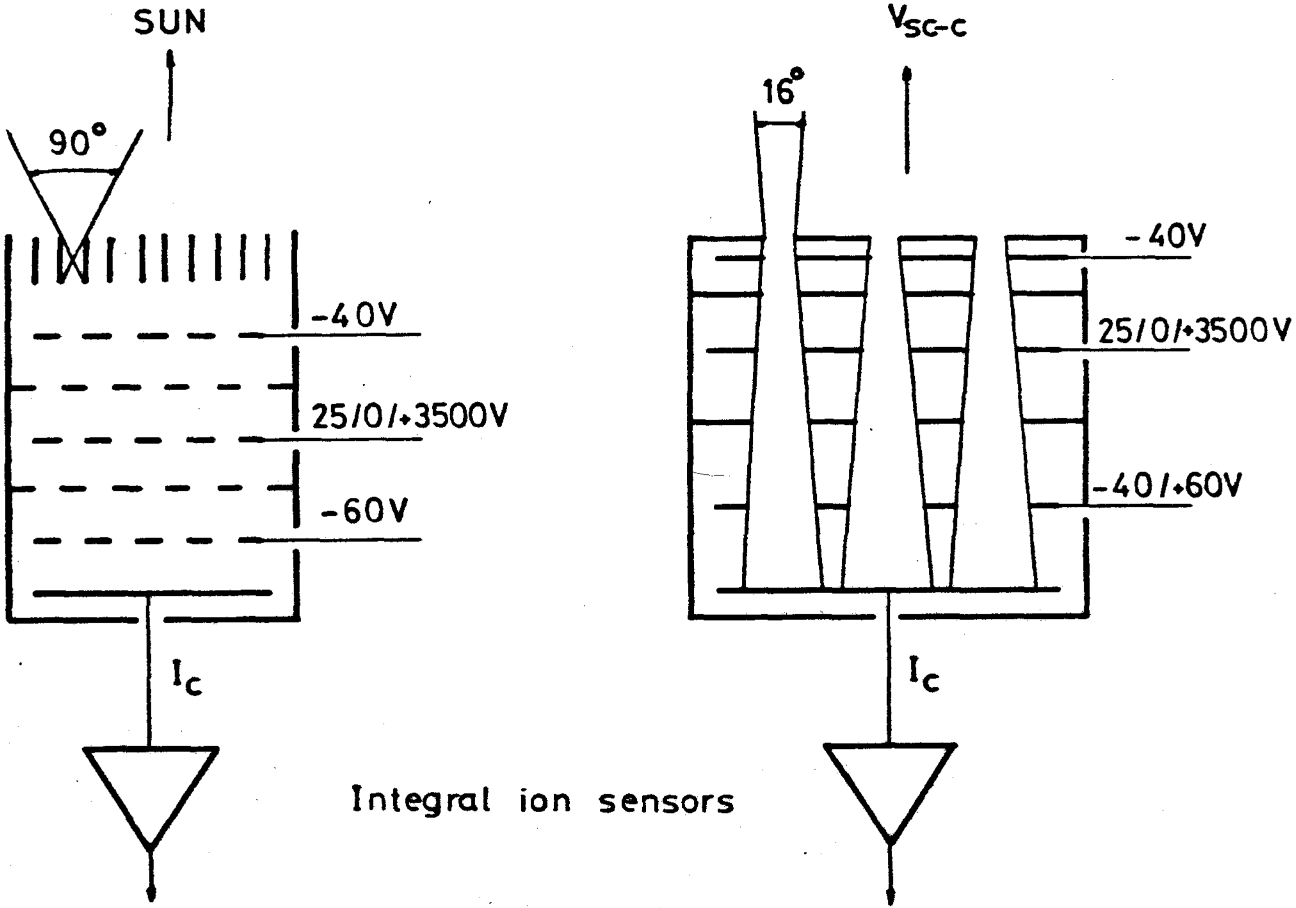

Fig. 5. Integral ions sensors

of the ion fluxes in the Sun-spacecraft direction. Detector (b) without honeycombs uses comparatively thick diaphragms with holes; the diameters of holes and the distances between diaphragm are chosen to provide a strong influence of electric potentials of the diaphragms on the charged particle fluxes. Impacts of heavy dust particles may create new holes in the diaphragms but cannot disturb the operation of the device.

Detector (b) can operate in four modes:

Mode (α): the total ion flux consisting of cometary ions and ions of local plasma environment of the spacecraft together with background (produced by secondary effects inside the analyser due to fluxes of neutrals and dust particles) is recorded;

Mode (β): the same as (α), but ions of local plasma environment are excluded by a V_R = +20 V retarding potential;

Mode (γ): all ions are rejected by V_R = 3,500 V, only background is recorded;

Mode (δ): the negative potential of the suppressor diaphragm is replaced by a positive potential of 40 V; in this case the collector current is created mainly by secondary electrons from the collector produced by cometary neutrals and dust particles.

Comparison of results of measurements in modes (α), (β), (γ) and (δ) will provide some information on cometary ion flux, the local plasma environment of the spacecraft and on fluxes of cometary neutrals and dust.

5. ELECTRONICS

The functional scheme of PLASMAG-1 is given in *Fig. 6*. The control unit is the main part of the instrument package. This unit is a microcomputer which consists of a microprocessor, operative memory, program memory, data storage and microprocessor interfaces.

The control unit provides data collection from the traps and energy spectrometers, classifies them in a certain order, keeps them in the data storage and sends the data to the TM-system in a convenient form for processing. The programs used for operating the control unit are kept in the program memory as are the high-

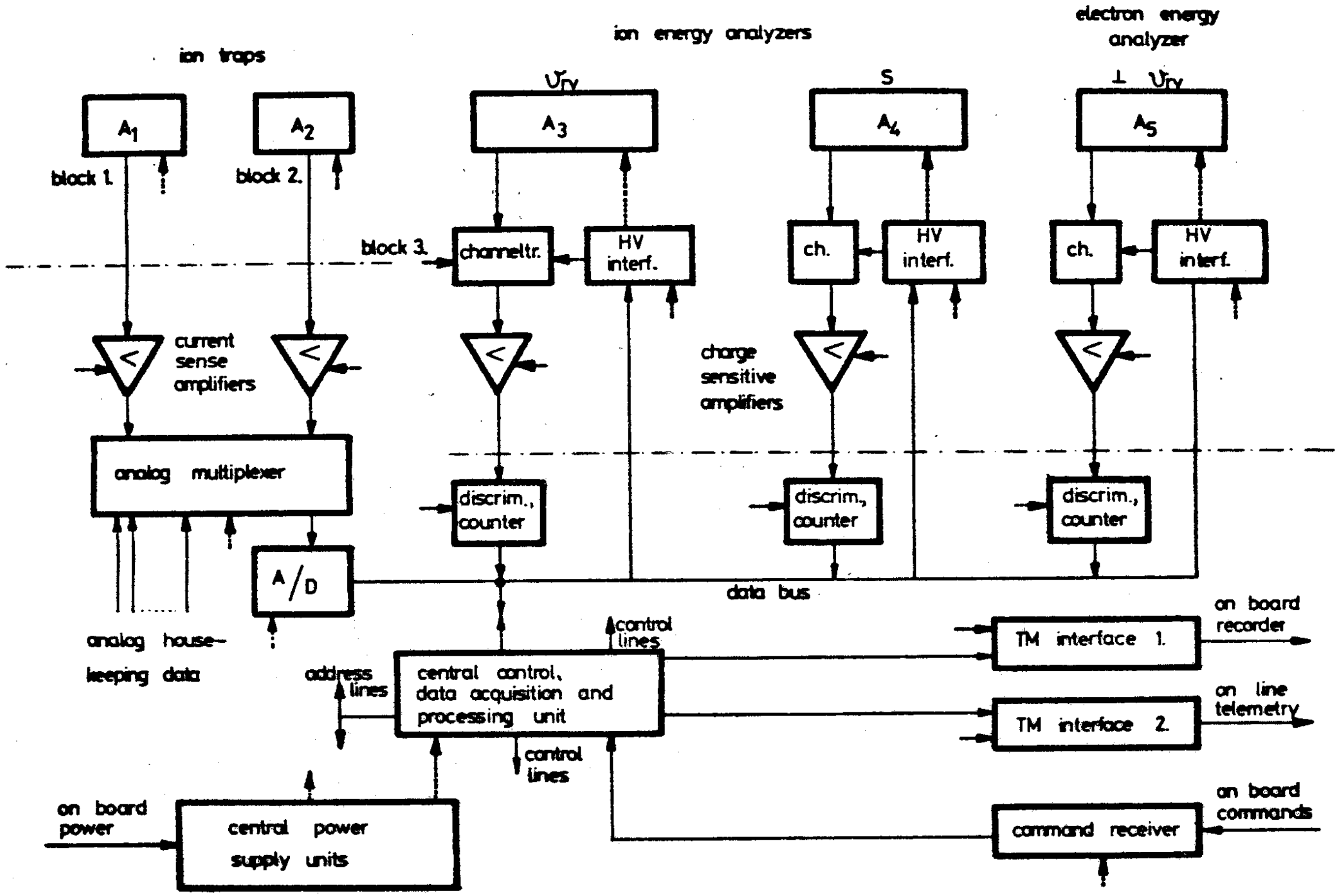

Fig. 6. Electronics block diagram

voltage sequences sent to the energy spectrometer deflection systems. This makes it possible to program the required nominal voltages without changing the hardware configuration. In a similar way the instrument operation sequences cyclogram can be changed within reasonable limits (exposition time of one energy interval number of intervals, etc.), i.e. the microprocessor unit provides high flexibility of the system, and allows for optimizing the system operation as a whole.

The control unit receives and processes (through the interface) the commands from ground and code messages that make it possible to change the operation mode of the instrument. The channeltron outputs are connected to charge-sensitive amplifiers ($8x10^{14}$-$8x10^{-11}$ Cb, 10^{6} Hz) followed by discriminator, the normalized output signals of which are counted in 19-digit counters. The counter content is quasilogarithmically compressed by the microprocessor (4 bit mantissa and 4 bit characteristic). These 8 bit numbers are recorded in the data storage. The trap collector currents amplified by sign sensitive logarithmic amplifiers reach the data storage in the form of a 9 digit word (including the current sign).

6. PROGRAMS OF OPERATION

There are 3 programs: One covers the last 3 hours of the flight to the comet (encounter program). All sensors are operating; total amount of information is 2 kbit/sec, the duration of one spectrum-measurement is 1 sec. Another program is for use during the 48 hours prior to encounter. It differs from the first program only by the amount of information, which is 150 times less than in program 1. The measurements are correspondingly slower: one spectrum is taken in 150 sec; the sensitivity of energy-spectrometers is 150 times higher than in the first program. The third of the three programs is used during cruise flight (until the second program begins to be used). Here, only those sensors which are pointed to the Sun and the electron analyser are switched on. Two spectra are measured by each spectrometer for a duration of 10 seconds every 20 minutes.

Once a day every spectrometer is calibrated as was described above. The amplifiers of the integral ion detectors are also calibrated.

The main metric characteristics of the Plasmag-1 package are given in Table 1.

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