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Hungarian Academy of Sciences

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ABSTRACT

The VEGA probe instrument package is intended to measure particles with energies less than 25 keV. Instruments designed to detect 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 energy spectrum of ions up to 25 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 analyzers 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 comet one complete set of electron and ion spectra will be measured every second.

АННОТАЦИЯ

На космическом аппарате ВЕГА будут установлены приборы для измерения ионов с энергиями от 50 эВ до 25 кэВ и электронов с энергиями от 3 эВ до 10 кэВ. К их числу относятся два ионных спектрометра - один ориентированный на Солнце для измерения энергетического распределения ионов с энергиями до 25 кэВ, а другой - направленный по вектору скорости космического аппарата относительно кометы - для определения энергетического распределения кометных ионов с энергиями до 3,5 кэВ и их масс от 1 до 100 м.е. Кроме того, два интегральных плазменных детектора (типа плоских анализаторов с тормозящими потенциалами) будут ориентированы также как ионные спектрометры. Электронный энерго-спектрометр будет ориентирован перпендикулярно направлению Солнце-космический аппарат. Вблизи кометы электронный и ионные спектры будут измеряться ежесекундно.

KIVONAT

A VEGA ürszonda e müszeregyüttese a 25 keV-nál kisebb energiáju részecskéket méri; iondetektorai az 50 eV - 25 keV, elektrondetektora pedig a 3 eV-3,5 eV energiatartományban müködik. A készülék két ionspektrométert tartalmaz. Az elsõ a Napra irányul, és a 25 keV-nál kisebb energiáju ionok energiaspektrumának mérésére szolgál. A második az ürhajó-üstökös relativ sebességvektorának irányába néz, és az üstökös 1 - 100 tömegszámu ionjainak tömeg- és energiaspektrumát méri. Ezen kivül a müszer két, fékezõpotenciálos, integráló tipusu plazmadetektort is tartalmaz, amelyek az ion-energia spektrométerekkel azonos irányitottságuak. Az elektron-energia spektrométer a Nap-ürhajó irányra merõleges. Az üstökös közelében a készülék másodpercenként egy teljes elektron- és ionspektrumot mér le.

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; a manner that can not 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 and on the location of the contact surface. Currently, data on 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 maximum dynamical range of the parameters being measured. This make it possible to study all regions of the near-cometary environment independent of model assumptions. As a consequence of this and weight limitations it was desirable to design rather simple light weight 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 analyzer, pointed towards the Sun, for ions with energies within the range from 50 eV to 25 keV;
- an electrostatic energy analyzer oriented along the spacecraft-comet relative velocity vector and 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 analyzer oriented normal to the sunward direction for electrons within energies ranging from 3 to 5000 eV;
- two integral plane multigrid analyzers (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 DYNAMICAL RANGE OF THE INSTRUMENT

The ion electrostatic analyzer oriented along the spacecraft velocity vector relative to the comet will have a minimum measurable number-density of 10^{-3} cm^{-3} and maximum of 10^5 cm^{-3}. (The dynamical range is therefore 10^8.) As one can see in the attendant paper (Gringauz, Verigin, Remizov [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.

Ion temperature of the near-cometary plasma according to models is estimated as 10^3 to 10^4 °K, i.e. $E = 0.1$ to 1.0 eV which is so much less than the energy of ions adequate to 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 is acting as a ram-mass-spectrometer with the energy resolution of 4 to 5 % corresponding to $\frac{m}{\Delta m}$ 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 in 120 energy intervals of one energy mass spectrum is 1 s, which corresponds to a spatial resolution of 80 km. The energy range of this ion energy analyzer is from 15 to 3500 eV. Since 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 analyzer 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 is varying, the angle of acceptance of this analyzer is broadened to ±25° by the use of electrostatic lens. This instrument together with the TÜNDE-instrument (the lower threshold of energy of which is 20 keV - see Somogyi et al. paper at this conference [3]) makes it possible to record ions arriving from the Sun with energies ranging from low to high values (500,000 eV and more).

The knowledge of solar wind velocity gives one possibility to judge on masses of registered by TÜNDE picked up ions of cometary origin.

The instrument sensitivity is from 10^4 to 10^8 $\mathrm{cm}^{-2}\mathrm{sec}^{-1}$.
The energy analyzer of electrons is oriented in a direction normal to the sunward direction. It 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 might clarify the situation with anomalous ionization of cometary neutrals.

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

The Plasmag-1 instrument package also includes two plane integral multi-electrode plasma detectors of RPA type which 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. It can measure these fluxes also 8 times per second. The characteristics of the device are summarized in Table N 1.

4. DESCRIPTION OF THE INSTRUMENT

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 analyzer. The instrument includes a 120 degree cylindrical deflecting system to which each second a series from 30 analysing potentials are fed that are distributed over the exponential low. The input area of the analyzer is 0.1 cm^2, the mean radius of curvature is 45 mm, and the energy gain is

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

(R_1 and R_2 are the radii of the internal and external deflecting plates.) The angular and energy resolution calculated using these (parameters) are ±3.5° and ±7 % respectively, and the energy-geometrical factor is 2×10^{-5} E cm^2 ster. keV.

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

To determine the degree of the degradation of channeltron, a special calibrating device is used; it is a separate cylindrical analyzer using the same channeltron whose particle source is a 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 the external signal. To provide a large dynamic range of measurements (it is especially required if the spacecraft approaches close to comet nucleus where the plasma density is expected to be high ($\sim10^5$ cm^{-3})), an additional regime of measurements with the sensitivity by two orders lower than the main regime is introduced.

This regime is performed for a 0.5 sec duration every 4 seconds and only for the measurements of electrons with energies up to 30 eV.

4.2 ION SPECTROMETERS

As it was mentioned earlier, to measure the ion components of solar wind and cometary plasma, two similar, simultaneously operating spectrometers (electrostatic analyzers) are used. The spacecraft three-axis stabilization and other above-mentioned limitations prevented us from measuring the three dimensional ion distribution function but permitted us to study only their energy distributions. 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 (by several orders of magnitude exceeding the ion flow) 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.

A necessarity of high sensitivity of the spectrometers and of the protection of its detector from the UV-radiation and, in the case of cometary ion spectrometer, from neutrals and dust particles forced us to use electrostatic analyzers using curved geometry for charged particle trajectories. A high resolution ΔE/E leads inevitably to a small angular aperture. A necessary wide angle of acceptance and a high resolution by energies can be obtained simultaneously by using not only an electrostatic analyzer but also an electrostatic lens near the aperture to widen the acceptance angle of the aperture.

A schematic of the solar wind ion spectrometer is given in *Fig. 2*. Each spectrometer is a hemispherical electrostatic analyzer at whose entrance a quadrupole electrostatic lens is mounted. The average radius of the curvature is R = 45 mm, and the gap between electrodes is R = 2.5 mm. Parameters of the analyzer and the electrostatic lens are selected so that their values E/eV should coincide and are equal to 7. One peculiarity of the spherical analyzer is its 'knife' edge angular aperture with a small input window. It makes 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 sensitivity to the directed flow of particles associated with the expansion of its angular aperture amounts to a value $\sim$5. The energy analysis of ion flux is performed by applying a series of positive voltages to the external electrode of the analyzer. In the fastest regime (near the comet) 30 levels of voltages are applied to the solar wind spectrometer for 1 sec and 120 levels are applied to the cold plasma spectrometer for 1 sec. In the latter case, 120 levels cover the whole dynamic range of energy measurements from 15 to 3500 eV without any gap. So, the measurements of any mass in the range from 1 to 100 a.u. is guaranteed. For the solar wind spectrometer 30 levels are distributed logarithmically over the energy range 50 eV - 25 keV.

However, a large number of levels is concentrated in the range below 5 keV where there is the peak in the solar wind ion energy distribution. *Fig. 3* gives calculational angular characteristics for the 'adjusted' analyzer for a switched on and switched off lens for two mutually perpendicular planes as an example of the operation of the combination of the electrostatic lens and the analyzer. Here is shown what happens when in one plane the angular characteristic constricts from 40° to 30° and in other one it expands from 4° to 30°. So, the spectrometer angular aperture represents the average between a circle and square with a diagonal of 30°. Each spectrometer is equipped with a calibration device with a tritium source of electrons. The calibration time schedule is similar to the regime for the electron spectrometer. In order to avoid the direct interaction of cometary neutrals and dust particles with the analyzer 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 analyzer (*Fig. 4*). As there are no grounds to expect high flows of ions in the direction from the Sun both in the solar wind and in the comet magnetosphere, in the solar wind spectrometer the dynamical range of the measurements is 10^5 (5×10^4-5×10^9 cm^{-2}ster^{-1}).

In the spectrometer for cometary ions a device is included to decrease the sensitivity by 3 orders; it is switched on periodically for one full spectrum measurement (1 sec) every 4 seconds. Unfortunately, such a regime is not optimum from the point of view of the performance but we regarded it as more reliable than an automatic switch on during the course of the experiment, when the ion fluxes increase. At the same time it can be expected that in the regime of high sensitivity (3 cycles) only for one or several intense peaks (possibly, H_2O^+, $CO_2{}^+$) the readings of instrument will be distorted and in any case correct spectra will be obtained in each 4th cycle. Therefore such a regime will result in a decrease of the time resolution (1 to 4 seconds) for intense peaks.

4.3 INTEGRAL PLASMA DETECTORS

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

In the detector (a) this defence is provided by short honeycombs installed in front of aperture; the angle of acceptance of detector is ±45°, the fluxes of ions with energies 20 eV 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 interaction of dust particles with the spacecraft: ions are retarded by positive potential of grid 3, electrons by negative potential of grid 1). During the encounter there will be 8 collector current measurements per second which enables one to estimate slow fluctuations of the ion fluxes in the Sun-spacecraft direction. In detector (b) there are no honeycombs, but the grids are replaced with comparatively thick diafragms with holes; diameters of holes and the distances between diafragms are chosen in such a way, which provides a strong influence of electric potentials of the diafragms to the charged particle fluxes. Impacts of comparatively heavy dust particles can create new holes in the diafragms but can not disturb the operation of 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 analyzer due to fluxes of neutrals and dust particles) is registered;

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

Mode (γ): all external to device ions are retarded by V_R = 3.500 V, only background is registered;

Mode (δ): the negative potential of suppressor diafragm is replaced by positive potential 40 V; in this case collector current is created mainly by secondary electrons from 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, 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. It is a microcomputer which consists of the 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 the certain order, keep them in the data storage and sends the data to the TM-system in the convenient form for prosecing. The programs of cyclograms used for operating the control unit are kept in the program memory. There are laso the laws of high-voltage nominals sent to the energy spectrometer deflection systems. This makes it possible to program the required voltage nominals without changing the hardware configuration. In a similar way the instrument operation cyclogram can be changed within reasonable limits (exposition time of one energy interval, number of intervals etc.), i.e. the microprocessor unit provides high mobility of the system, allows for optimizing the system operation as a whole taking into account the peculiarities of sensor operation after the laboratory experiments and calibration of the instruments.

The control unit receives and processes (through the interface) the commands from ground and code messages that makes it possible to change the operation mode of the instrument. The channeltron outputs are connected to the charge-sensitive amplifier (8×10^{14}-8×10^{-11} Cb, 10^6 Hz) and then to the discriminator. After the discriminator the normalized signals are counted by 19-digit counters. The counted pulses are converted by the microprocessor to the normalized form (4 digits mantissa and 4 digits characteristic). These 8 digit numbers are recorded in the data storage. The trap collector currents through the sign sensitive logarithmic amplifiers get to the data storage in the form of 9 digit work (including the current sign).

6. PROGRAMS OF OPERATION

There are 3 programs. The first one is used during the last 3 hours of flight to comet (encounter program). All sensors are operating; total amount of information is 2 kbit/sec. The duration of one spectrum-measurement is 1 sec.

Second program begins to be used in 48 hours before encounter. It differs from the first program only by amount of information which is 150 times less than in program 1. The measurement are correspondly slower: one spectrum is measured in 150 sec; the sensitivity of energy-spectrometers is 150 times larger than in the first program. The third program is used during the flight on the way Earth-Venus-Comet (till the second program begins to be used). In this program only pointed to Sun sensors (and electron analyzer) are switched on. Two spectra are measured by each spectrometer during 10 second every 20 minutes. Once a day every spectrometer is calibrated as was described above. The amplifiers of integral ion detectors are also calibrated.

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

REFERENCES

[1] R.Z. Sagdeev, G.A. Skuridin, A.A. Galeev, V.I. Moroz, V.I. Shevchenko, V.D. Shapiro, B.S. Novicov, G.A. Avanesov, T.A. Chugarinova, P.E. Elyasbery, A.A. Suhanov, S.N. Rodinov, "On encounter with comet Halley in 1986 (Strategy of studying)" Preprint IAF-81-200, Rome, Italy, September 6-16, 1981

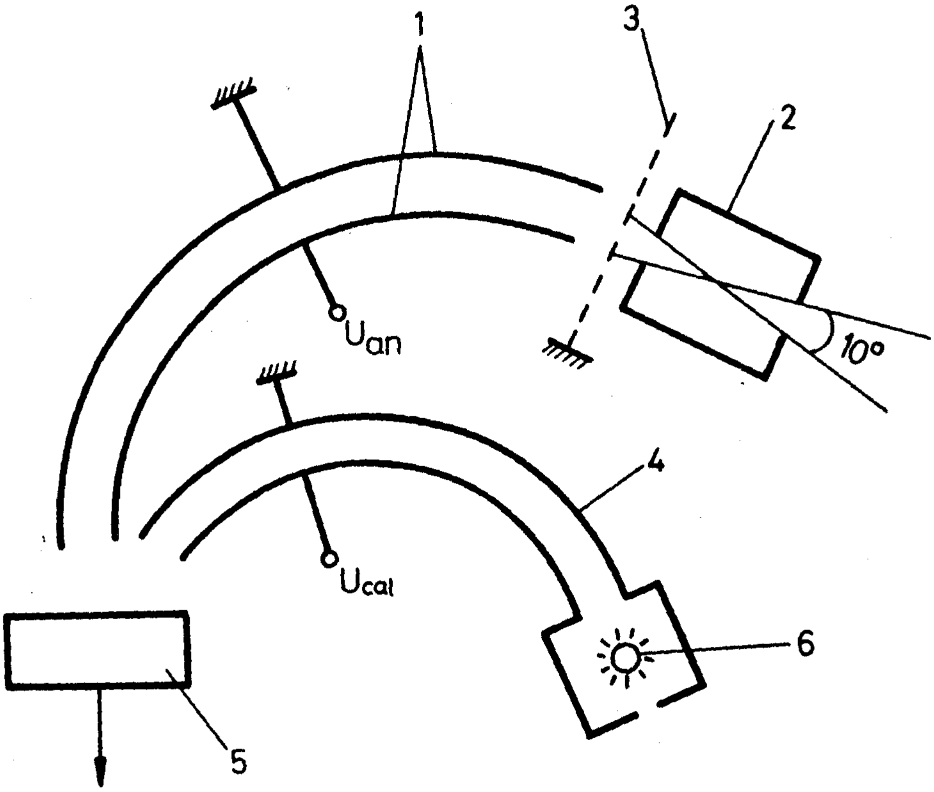
[2] K.I. Gringauz, M.I. Verigin, A.P. Remizov, Mass spectrometry of newly ionized cometary gas by plasma instruments onboard Giotto and VEGA space probes (presented to International Conference on Cometary Exploration, Budapest, 15-20 November, 1982)

[3] A. Somogyi, V.V. Afonin, J. Erő, T. Gombosi, K.I. Gringauz, K. Kecskemety, E. Keppler, I.N. Klimenko, Yu.I. Logachev, A.P. Remizov, A.K. Richter, G.A. Skuridin, V.G. Stolpovsky, G.A. Vladimirova, V.P. Wenczel, J. Windberg, The VEGA probe energetic particle telescope (presented to International Conference on Cometary Exploration, Budapest, 15-20 November, 1982)

Table N 1

Parameters	Integral Detectors		Energy spectrometers		
	to the Sun	to $\vec{V}_{SC\text{-}com}$	ions along to $\vec{V}_{SC\text{-}com}$	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. $M/\Delta M = 25$		
dynamical 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) $cm^{-2}ster^{-1}s^{-1}$

VEGA "Plasmag-1" Experiment

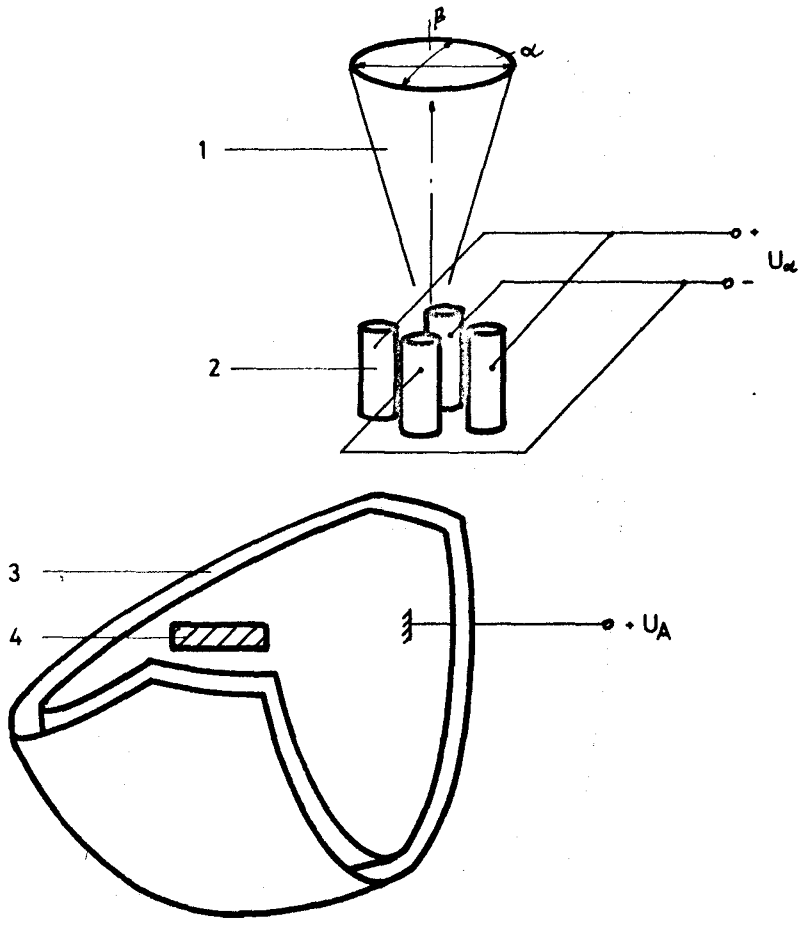


1 — deflecting plates for energy analysis
2 — electrostatic lenses
3 — grid
4 — deflecting plates for calibration
5 — channeltron
6 — electron source for calibration

Electrostatic particle energy analyser

Fig. 1

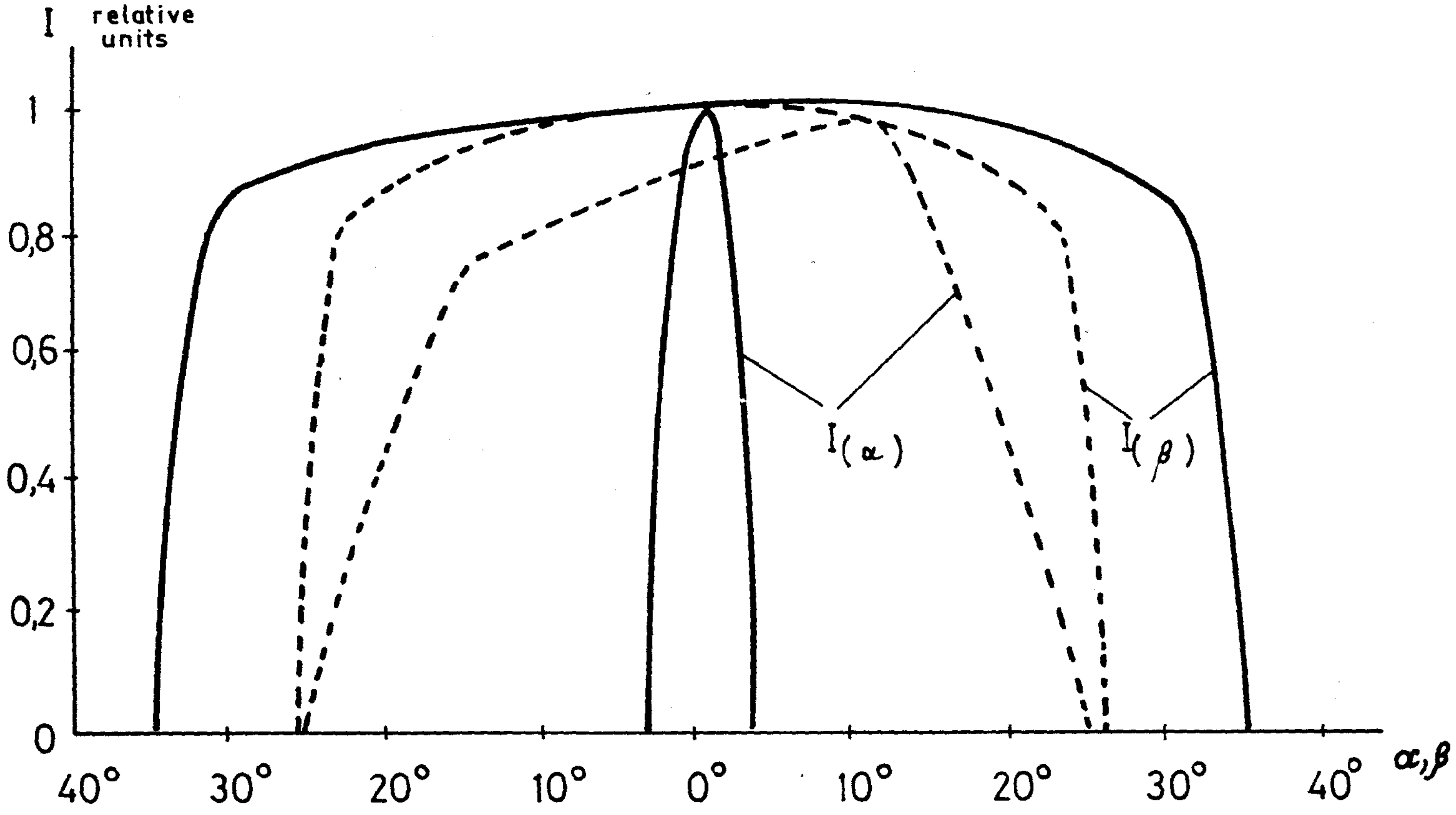
VEGA "Plasmag-1" Experiment



1. acceptance angle
2. quadrupol lens
3. analyzing spherical system
4. channeltron

Fig. 2

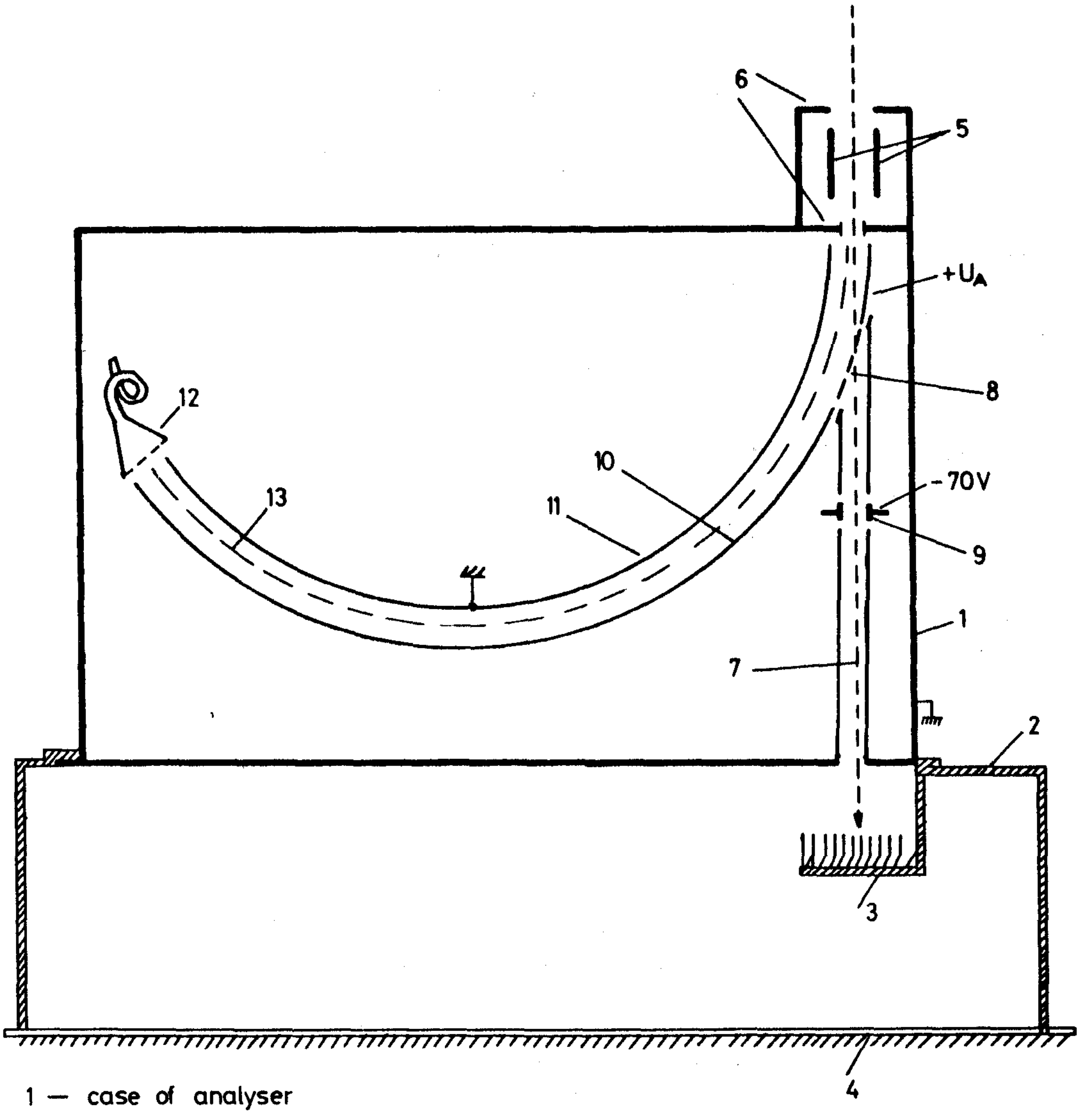
VEGA "Plasmag-1" Experiment



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

Fig. 3

VEGA "Plasmag-1" Experiment



1 — case of analyser
2 — case of electronics
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

Ion analyser

Fig. 4

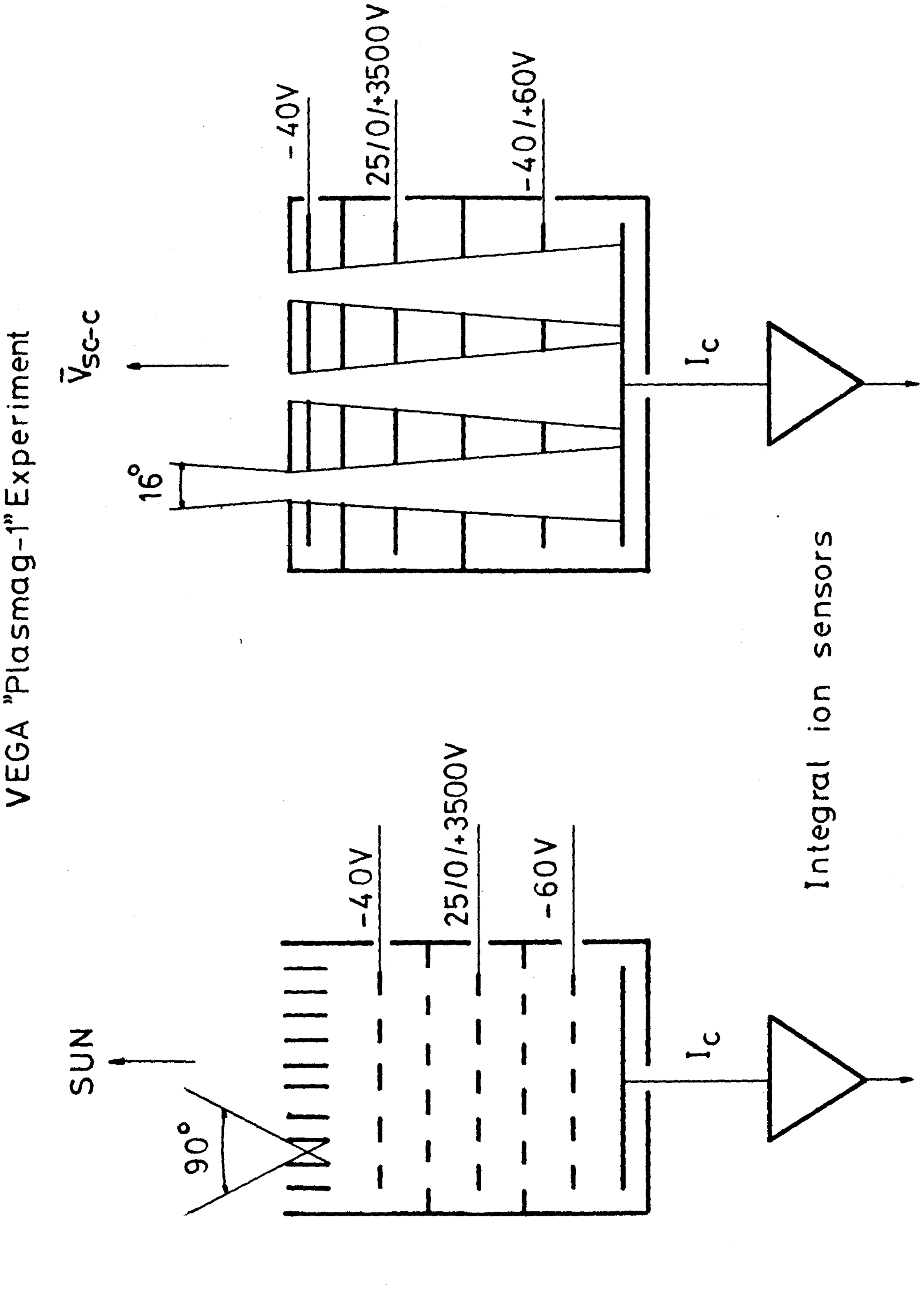

VEGA "Plasmag-1" Experiment
SUN
90°
-40V
25/0/+3500V
-60V
I_c
$\bar{V}_{sc-c}$
16°
-40V
25/0/+3500V
-40/+60V
I_c
Integral ion sensors

Fig. 5

VEGA "Plasmag-1" Experiment

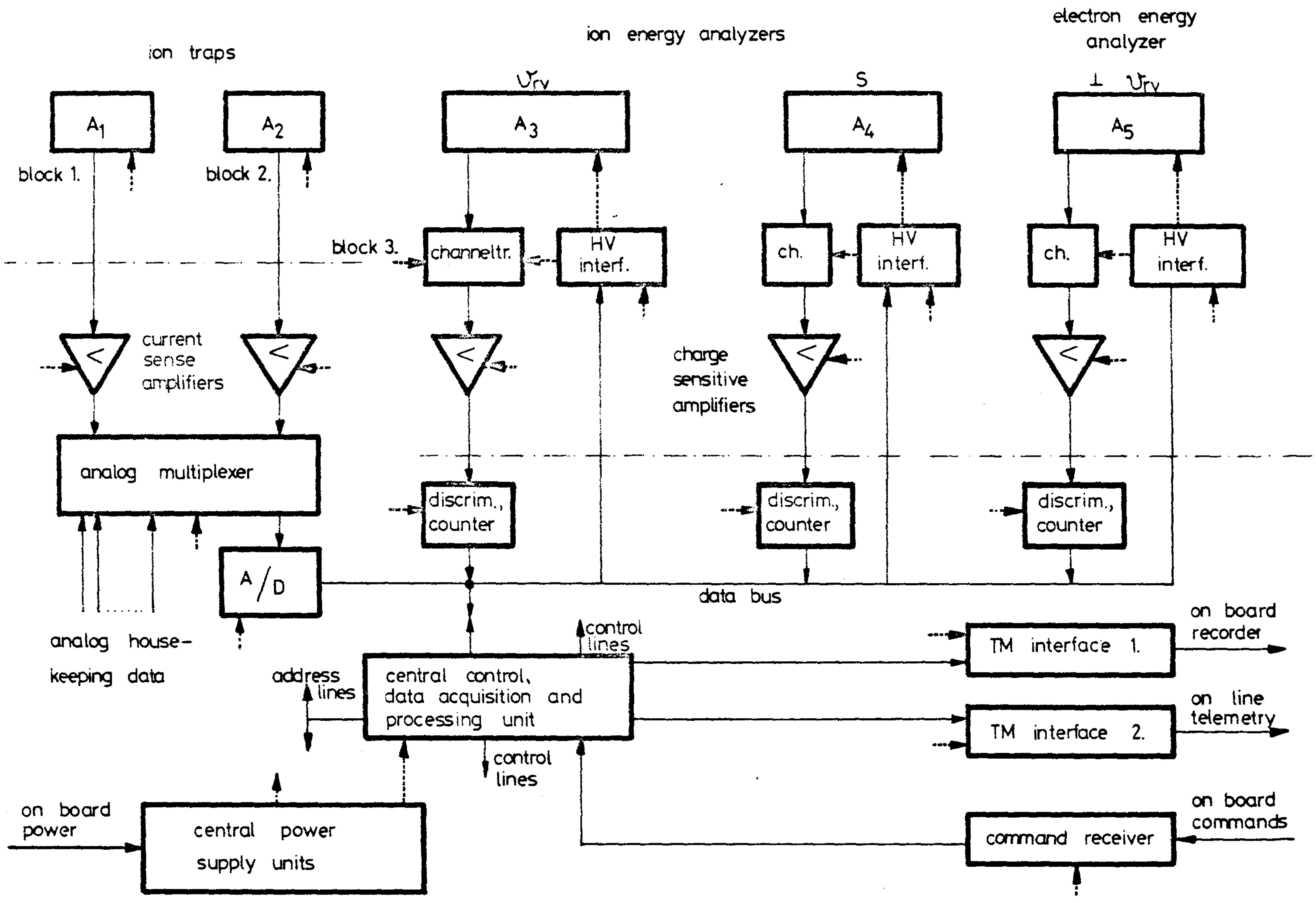


Fig. 6 Electronics Block Diagram