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# The Vega Missions *

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## 1. Introduction

A unique opportunity to combine missions to Venus and Comet Halley is available in 1985-1986 by employing a two-element space vehicle consisting of a Venus lander and a Halley flyby probe. This mission is being conducted by the USSR with the cooperation of a number of other countries.

Two spacecraft, Vega-1 and Vega-2*, have been launched aboard Proton rockets from Baykonour (Kazhakstan), on 15 and 21 December 1984, respectively. The two spacecraft are identical and the ’redundancy’ is aimed at increasing the overall reliability of the scientific mission. In June 1985, the landers were separated from the Halley probes in the vicinity of Venus. They were injected into the planet’s atmosphere to perform measurements until after surface impact. During their descent, the landers each released a balloon, to drift in the planet’s atmosphere. These balloons were tracked with the help of an international Very-Long-Baseline Interterometry (VLBI) network.

After relaying the lander telemetries towards the Earth, the Halley probes continued their journey towards the comet, following an orbital correction and a gravitational manoeuvre around Venus. The cometary flyby will occur in the period 6-12 March 1986, at distances of the order of 10,000 km from the nucleus and with a relative velocity of 78 km/s.

One of the Vega programme’s aims was study of Venus’ atmospheric composition and circulation, clouds and planetary surface. This article, however, is devoted entirely to the second aim of the mission, the exploration of Comet Halley.

The scientific objectives of the Vega cometary investigation are:
(i) determination of the physical parameters of the nucleus: dimensions, shape, temperature and surface properties
(ii) study of the structure and dynamics of the coma around the nucleus
(iii) definition of the gas composition in the close vicinity of the nucleus and the nature of the parent molecules
(iv) study of the dust particles’ composition and mass distribution as functions of the distance to the nucleus, and
(v) study of the interaction of the solar wind with the atmosphere and ionosphere of the comet.

The Halley probes are three-axis-stabilized and their orientation will be defined with an accuracy of 1deg during Halley flyby. The optical instruments are mounted on a pointing platform which can track the nucleus with an angular accuracy of the order of 5 arcmin. The other instruments are mounted on the main structure of the probes. The data are transmitted via two independent telemetry links, with capacities of 3072 bit/s and 65 536 bit/s, respectively. Each Halley probe carries a complement of 14 experiments, which are listed in Table 1.

## 2. The scientific payload

### 2.1 Television system (TVS)

The purpose of the television system (TVS) is to detect the cometary nucleus, measure its dimensions and albedo, and study the structure and dynamics of the central part of the coma. This instrument also constitutes the sensor for the servo-system that controls the motion of the pointing platform, on which it is mounted together with the two other optical instruments (IKS and TKS).

The television system consists of two telescopes, one narrow-angle camera (TVY) for high-resolution imaging of the nucleus, and one large-angle camera (TDN) for detecting and tracking the comet (Fig. 1). The TVY optics have a reflecting objective with a focal length of 1200 mm and a detector which yields an average angular resolution of 3 arcsec, i.e. a spatial resolution of the order of 150 m at the nominal flyby distance of 10,000 km. The maximum angular dimension of the nucleus and its near environment is expected to be 5 arcmin at closest approach, and the pointing error is estimated to be +/- 5 arcmin. The field of view of the TVY must therefore be not less than 15 arcmin.

The TDN has a refractory objective with a focal length of 150 mm. It is characterized by an angular resolution of 0.5 arcmin, required for early acquisition of the comet and its nucleus, and a 2deg field of view imposed by the constraints associated with control of the pointing platform.

The light collected by each telescope is divided into two paths by a beam splitter. One channel is fitted with a fixed filter, the other has a set of eight filters mounted on a rotating wheel, to yield a spectral analysis of the signal. The images are formed on area CCDs cooled by a passive radiator regulated by a Peltier plate. The commutable filters of the TDN have an additional function, namely to adjust the amount of light collected by the detector. This channel is operated autonomously and performs an independent analysis of the video signal, thus providing redundant information to the platform pointing system for the sake of reliability.

The signals delivered by the three other TDN and TVY channels are handled by the same microprocessor system which analyzes the images and generates the commands that control the motion of the platform.

The TVS electronics include a 816 kbit memory to store both data and programs. The main characteristics of the TVS are given in Table 2.

Table 1. VEGA scientific payload

| Acronym | Experiment | Mass (kg) | Power (W) | Direct telemetry (bit/s) | Recorded telemetry (bit/20 min) | Collaborating (Principal In |
|---|---|---|---|---|---|---|
| TVS | Television System | 32 | 50 | 32768 | | LAS, Marseill<br>Central Resea<br>Hungary (L. S<br>IKI, Moscow, |
| IKS | Infrared Spectrometer | l8 | 18 | 2048 | 4320 | Observatoire<br>IKI, Moscow, |
| TKS | Three-Channel | 14 | 30 | 12288 | | Observatoire |

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* The name Vega is a contraction of the Russian words Venera (Venus) and Gallei (Halley)

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Spectrometer |  |  |  |  | IKI, Moscow,<br>Bulgaria (M. |
| PHOTON | Shield Penetration Detector | 2 | 4 | 108 |  | USSR |
| DUCMA | Dust Particle Detector | 3 | 2 | 100 | 100 | University of<br>MPI, Lindau,<br>IKI, Moscow,<br>Central Resea |
| SP-2 | Dust Particle Detector | 4 | 4 | 1024 | 2160 | IKI, Leningra |
| SP-1 | Dust Particle Detector | 2 | l | 150 | 2160 | IKI, Moscow, |
| PUMA | Dust Mass Spectrometer | 19 | 31 | 10240 |  | MPI, Heidelbe<br>Serv d’Aero,<br>11(1, Moscow, |
| ING | Neutral Gas Mass Spectrometer | 7 | 8 | 1024 | 1080 | MPI, Lindau,<br>Central Resea<br>IKI, Moscow,<br>University of |
| PM-1 | Plasma Energy Analyser | 9 | 8 | 2048 | 15120 | IKI, Moscow,<br>Central Resea<br>MPI, Lindau,<br>ESA Space Sci |
| TN-M | Energetic Particle Analyzer | 5 | 6 | 512 | 6480 | Central Resea<br>Hungary (A. S<br>IKI, Moscow,<br>MPI, Lindau,<br>ESA Space Sci<br>Nuclear Resea |
| MISCHA | Magnetometer | 4 | 6 | 512 | 2160 | Space Res Ins<br>Izmiran, Troi |
| APV-N | Wave and Plasma Analyser | 5 | 8 | 2048 | 28080 | IKI, Moscow,<br>Aviation Inst<br>Geophysical S |
| APV-V | Wave and Plasma Analyser | 3 | 2 | 512 | 15120 | ESA Space Sci<br>LPCE, Orleans<br>Izmiran, Troi |

Figure 1. The telescopes of the television system (TVS): (a) high-resolution camera, (b) low-resolution camera

Table 2. Television System characteristics

| Camera system | High resolution |  | Low resolution |  |
|---|---|---|---|---|
| Objective | Reflector |  | Refractor |  |
| Focal distance | 1200 mm |  | 150 mm |  |
| Aperture | 240 mm |  | 50 mm |  |
| Relative aperture | 1:5, effective 1:6.5 |  | 1:3 |  |
| Channel | Multispectral | Integral | Multispectral | Integral |
| Spectral range, micro m | 0.4-1.1 | 0.63-0.76 | (1) 0.4-1.1<br>(2)0.63-0.76 | 0.63-0.76 |
| Number of filters | 8 | 1 | Range (1):1<br>Range (2):7 | 1 |

| | | | |
|---|---|---|---|
| Field of view | 26.4’x39.6’ | 211’x316’ | 211’x158’ |
| Resolution | 3.1"x4.1" | 24.75"x33" | 99"x132" |
| Shutter | Mechanical | | Electronic |
| Exposure time range | 0.01-163 s | | 6-800 ms |
| Detector area | 5l2x512 pixels | | 512x256 pixels |
| Data compression | Floating window of 128 X 128 pixels around brightest point | | Full image of 128x128 pixels after integration of 4x2 pixels |

## 2.2 The infrared spectrometer (IKS)

The infrared spectrometer is designed to study the radiation from the inner coma, in the wavelength range 2.5-12 micro m. The instrument includes two high-resolution spectral channels for the chemical analysis of the cometary matter, gas and dust, and an image modulation channel for determination of the size of and thermal emission from the nucleus.

The light that exits from the telescope is divided into three by means of two beam-splitters. The secondary beams are then focussed on a wheel that rotates at the rate of 8 rev/sec and carries three rings, namely two circular variable filters and one image modulator. Behind the encoding wheel, the beams enter a cryostat which cools the three detectors (Fig. 2).

The two filters cover the ranges 2.5-5 micro m and 6-12 micro m, which include the emission bands of the parent molecules. The long-wave channel can detect water ice and the short-wave channel can be used to identify a number of minerals, such as silicates. The imaging channel does not resolve details of the nucleus, the objective being to derive its most important parameters, size, shape, temperature and optical properties in the infrared. To accommodate the nucleus pointing uncertainties, a field of view of 1deg is judged necessary and an angular resolution of 1 arcmin satisfactory. More instrument characteristics are given in Table 3.

Since the sensitivity of the instruments is degraded by four to five orders of magnitude between 77 K and room temperature, it appears mandatory to cool the detectors during the two measuring sequences using the Joule-Thomson expansion of nitrogen. For that purpose, 2 l of nitrogen are stored in four tanks at a pressure of 350 atm. The detector temperatures reach stability within 25 min (to +/- 0.1deg) and can be maintained so for 3 h.

## 2.3 The three-channel spectrometer (TKS)

The objectives of the three-channel spectrometer are to define the chemical composition of the cometary coma and tail, to identify the polarization and spectrum of the light component diffused by the dust, to detect the primary molecules, and to obtain the spectral signature of the nucleus and its environment.

Figure 2. Optical system of the infrared
spectrometer (IKS)

The TKS instrument includes a Cassegrain refractory telescope. The secondary mirror can be tilted about two axes in increments of 8 arcmin. It covers a field of 2deg x 1.5deg, equivalent to an area of 350x260 km**2 at a distance of 10**4 km. The spectral map is made up of 7 lines and each line consists of 15 locations. The measurement cycle at each location lasts 5 s, so that a complete spectral map is taken every 8 min 45 s. Three slits located in the focal plane of the objective form the beams which enter the three channels of the spectrometer, as illustrated in Figure 3.

The visible and ultraviolet channels are similar and symmetrically arranged. A holographic diffracting array makes a spectral image of the entrance slit on a photocathode system. The electron flows delivered by the elements of the photocathode are first amplified by four orders of magnitude and subsequently accelerated to an energy of several keV before impacting on a luminescent screen. Optical fibres then transfer the spectrum from the screen to a linear CCD. Each channel delivers a spectrum of 700 points every 5 s.

The UV measurements provide information about the fluorescence spectra of a number of atoms, radicals and ions, whereas the visible channel gives the spectrum of the light diffused by the dust and the nucleus.

The infrared and polarization channel makes use of an interferential circular filter, which sweeps the spectrum as it rotates. Two sectors of this wheel are occupied by narrow-band filters, which are transparent for the wavelengths 560 and 920 Nm; each of these two filters is itself divided into three zones covered with various polaroids. The filter wheel is associated with a modulator, which rotates at a faster rate, allowing the detected signal to be differentiated more easily from the superimposed noise. A fraction of the light entering the infrared polarisation channel is deflected by a beam splitter and focussed on a detector which yields the integral signal received over the whole infrared range.

Table 3. Infrared Spectrometer characteristics

| | |
|---|---|
| Objective | Ritchey-Chretien |
| Primary mirror aperture | 140 mm |
| Secondary mirror aperture | 56 mm |
| Focal distance | 538.1 mm |
| Field of view | 1deg |
| Resolution | Diffraction limited |

| Channel | Imaging | Short wavelength | Long wavelength |
|---|---|---|---|
| Wavelength. micro m | 7-14 | 2.5-5 | 6-12 |
| Spectral resolution, lambda/delta lambda | 2.5 | 50 | 50 |
| Optical transmission | 0.10 | 0.39 | 0.33 |
| Detector | HgCdTe | In Sb | HgCdTe |
| Chip area, mm**2 | 2x2 | 2x2 | 2x2 |
| Geometrical factor, cm**2 sr | 0.046 | 0.045 | 0.038 |
| IR background, W | 1.2x10**-4 | 3.5x10**-6 | 9.7x10**-5 |
| Photon noise, W | 1.3x10**-12 | 4x10**-13 | 1.4x10**-12 |
| Nominal NEP, WHz**-1/2 | 4x10**-12 at 6 kHz | 2x10**-12 at 200 Hz | 1x10**-11 at 200 Hz |

Figure 3. Schematic of the three-channel spectrometer (TKS)

The infrared signal contains spectral components that characterize the vibration modes of a number of parent molecules. The map of the integral infrared flux will be used to locate the position of the nucleus. since the flux is proportional to the columnar dust density integrated along the line of sight. Polarization measurements will complete this information by giving indications of the size of the dust particles.

The main characteristics of the TKS instrument are summarized in Table 4.

Table 4. The Channel Spectrometer characteristics

| | |
|---|---|
| Objective | Cassegrain |
| Primary mirror aperture | 100 mm |
| Secondary mirror aperture | 43 mm |
| Focal distance | 350 mm |

| | |
|---|---|
| Field of view | 2.5deg x 1.5deg (using tiltable secondary minor) |

| Channel | Ultraviolet | Visible | Infrared | Polarimeter |
|---|---|---|---|---|
| Spectral range, Nm | 115-290 | 280-700 | 900-1800 | 560-920 |
| Spect res, lambda/delta lambda | 700 | 700 | 100 | 100 |
| Sensitivity, Rayleigh | 200 | 200 | 10**6 | 10**6 |
| Spatial res., km**2, 10**4 km | 75x3 | 75x3 | 300x30 | 300x30 |
| Detector | Photocathode & linear CCD | Photocathode & linear CCD | Ge, photodiode | Ge, photodiode |

## 2.4 The shield penetration detector (PHOTON)

The objectives of this experiment are: (i) to measure the flux density of dust particles in the high-mass range, (ii) to understand the mechanism of high-velocity impacts on the spacecraft surface, and (iii) to establish the performance of the meteoroid shields protecting a number of subsystems.

The impact surface is a circular nickel sheet, 0.1 mm thick, which makes an angle of 52deg with the Sun's direction and 60deg with the dust flow direction (Fig. 4). A piezoelectric element and an optical system which consists of a silicium photoemissive diode and a parabolic mirror with a focal distance of 7.5 cm are mounted on the back side of this foil. The whole detector is mechanically decoupled from the structure.

Figure 4. View of the shield penetration detector (PHOTON)

Table 5. Shield Penetration Detector characteristics

| | |
|---|---|
| Target material | Nickel |
| Target thickness | 0.1 mm |
| Sensor effective area | 137 cm**2 |
| Dust mass range | 10**-10 -10**-5g |
| Volumic mass density range | 0.8-3.5 g/cm**3 |

The dust angle of incidence is such that the impact ejecta are collected by the side wall of the chamber, thus minimizing the degradation of the mirror surface. The acoustical signal is recorded by the piezo-electric element and the luminous flash associated with the impact and the increment in solar illumination due to the perforation are measured with the optical system. The technical parameters of this experiment are given in Table 5.

Table 6. Dust Particle Detector and Mass Analyser characteristics

| | |
|---|---|
| Impact detector | 28 micro m**2 PVDF foil |
| Detector area | 75cm**2 |
| Maximum count rate | 10**5/s |
| Differential dust mass range | 1.5x10**-13 -9x10**-13 g |
| | 9x10**-13 -9x10**-12 g |
| | 9x10**-12 -9x10**-11 g |
| Integral dust mass range | >9x10**-11 g |
| Integration time for flux measurements at encounter | 2 s |

### 2.5 The dust-particle counter and mass analyzer (DUCMA)

This instrument measures the count rate and mass distribution of dust particles in the cometary environment.

The detector is a 28 micro m thick film of polarized polyvinylidene fluoride (PVDF), covered on each face with a metallic conducting coating. A dust particle impacting the detector will displace a small volume of polarized material in the bulk of the detector, which then results in a fast depolarization signal whose amplitude is a known function of the particle mass and velocity. Electronic circuits measure the pulse height and accumulate pulse events above four different threshold levels. Since the relative impact velocity is known (i.e. the comet-spacecraft velocity), the mass is determined directly from the known mass/velocity relationship for these detectors.

The detector assembly is shown in Figure 5. It consists of the dust detector (M), and a small anti-coincidence detector (V), mounted perpendicular to the direction of arrival of the dust particles. The purpose of the small detector is to detect very large mechanical shocks on the spacecraft which might trigger the most sensitive level of the dust detector.

Further technical details are given in Table 6.

The detector also includes an anticoincidence system mounted in a direction perpendicular to the direction of arrival of the dust particles.

This instrument was selected one year before launch and could still be considered at this late stage because it did not require any direct telemetry or telecommand interface with the spacecraft. Its inclusion was facilitated because it was allowed to share the data format and telecommands initially allocated to the ING instrument.

Figure 5. The detector of the dust-particle
analyzer (DUCMA)

### 2.6 The dust-particle impact detector (SP-2)

The objective of this instrument is to measure the flux and the mass distribution of the dust particles. The counter makes use of acoustical and plasma detectors (Fig. 6). The acoustical detector consists of three piezo-electric elements mounted on a membrane (3), two of these sensors (4) are connected to two identical recording circuits in order to improve the overall reliability of the system; the third element (5) is used as a stimuli source for calibration purposes. The membrane is mounted in a frame (l) which damps the mechanical oscillations and improves the counting rate. The detector assembly is fixed to the electronics box (6) by means of three acoustical insulators (2). Each piezo-electric element delivers a signal which is fed into a narrow-band amplifier working at a frequency of about 160 kHz. The output signal is split into l6 channels, which have their sensitivity thresholds logarithmically distributed across the whole dynamic range.

Four identical impact plasma detectors are mounted at the periphery of the acoustical detector. They are associated in pairs and connected to identical electronic circuits. The entrance to each detector is protected against the environmental plasma by a system of deflecting electrodes and grids (7,8). The ions and electrons generated by each particle impact are separated and collected by a grid (9) and a target (10), between which a potential difference of 2 kV is applied. The electron pulse detected by the lower electrode constitutes the input signal, which is analyzed in several channels with different sensitivity thresholds.

The characteristic features of SP-2 are listed in Table 7.

Table 7. Dust Particle Impact Detector characteristics

| Detector | Piezo-electric | Impact plasma |
|---|---|---|
| Total sensor area | 500 cm**2 | 40 cm**2 |
| Maximum count rate | 4095 s**-1 | 65500 s**-1 |
| Integration time | 1 s | 1 s |
| Mass resolution,m/deltam | 2.82 | 10 |

| | | |
|---|---|---|
| Number of channels | 16 | 6 |
| Dynamic range | 2x10**-6 - 3x10**-3 g | 3xl0**-16 - 3x10**-11 g |

Figure 6. General view and schematic of the dust-particle impact experiment (SP-2). See text for details

### 2.7 The dust-particle impact plasma detector (SP-1)

The main scientific objective of the SP-1 instrument is similar to that of SP-2, namely to measure the flux and mass distribution of the dust particles.

This instrument detects the electric charges contained in the plasma cloud generated by a solid particle impacting on a gold target. The principle of this technique is similar to that adopted for the impact plasma detectors of SP-2. The magnitude of the positive and negative charges is proportional to the mass of the particle Q=Am, where A= 10**3C/s for an impact velocity of 78 km/s.

The SP-1 system includes two similar detectors (Fig. 7). Each unit is made up of a base plate (1) covered by a gold target (2) at zero potential, perpendicular to the dust flow, and an array of strip collectors (4). The collectors are parallel to the dust flow; they are mounted on an insulator (3) and their edge is protected from impacts by a shield (5) connected electrically to the structure. Adjacent collectors are biased at potentials of 30 V, with opposite polarities. The two sets of electrodes in each detector detect a positive and a negative current pulse, which are analyzed and recorded by the electronics unit. The entrance to one detector is covered by a plastic foil, to obtain additional information on density and/or calibration factor. The characteristic parameters of SP-1 are given in Table 8.

Table 8. Dust Particle Impact Plasma Detector characteristics

| | |
|---|---|
| Target material | Gold (0.1 mm) |
| Total sensor area | 160 cm**2, one sensor covered with 0.6 and 2 micro m thick plastic foil on Vegas-1 and 2, resp. |
| Impact charge range | 3x10**-14 - 10**-8 C |
| Estimated mass range | 3x10**-17 - 10**-11 g |
| Integration time | 2 s (high data rate)<br>2.5 min (low data rate) |

Figure 7. General view of the dust-impact plasma instrument (SP-1) and details of the detector. Dimensions are given in mm. See text for details

### 2.8 The dust mass spectrometer (PUMA)

The dust mass spectrometer measures the chemical composition, the size and the spatial density of solid particles using a time-of-flight technique, with particular emphasis on the determination of the Li, C and B isotopic ratios. The operating principle of PUMA, illustrated in Figure 8a, is similar to that of the PIA instrument flown on Giotto.

The dust particles enter through a baffle and impact on a silver target (M) at a speed of 78 km/s. The particles and a certain amount of the target material are vaporized and partly ionized. The two Vega spacecraft have different targets (Fig. 8b); one type is mounted in a cartridge as in the PIA, the second has a corrugated surface such that a larger amount of projectile ions enter the analyzer. The target is at + 1020 V; the ions are accelerated by a grid (1), which is held at a potential of -2000 V, and enter the field-free drift tube at zero potential (4). These charged particles are sent by the electrostatic reflector (5) into the second drift tube (6) and on towards the detector (7).

The ions trajectories are focused by the lenses (9), (10) and (11). A set of three electrodes (12), consisting of an inner grid at +1000 V between two grids at zero potential, prevents ions with energies less than 1 keV from reaching the detector.

The geometry of the reflector is designed in such a way as to bunch ions of the same species (particles with energies E>E(0) travel a larger distance than those with energies E<E(0)) and to eliminate those with energies that deviate too much from E(0). The purpose of this mirror system is to reduce the dispersion of the flight times for particles having the same charge-to-mass ratios. The reflector potential is switched between 1000 V and 1100 V every 30 s, in order to compensate for the higher energies of ions created by the impacts of larger particles.

The time-of-flight is measured with reference to three signals: the light flash recorded by the photomultiplier (3), the pulses detected by the target (M), and the accelerating grid (1). The signals induced in these sensors, in the first lens (9), in the ejecta trap (8) and in the detector (7), which are illustrated qualitatively in Figure 8c, are used to characterize the mass of the particles.

Additional information about PUMA is given in Table 9.

Figure 8. The dust mass spectrometer (PUMA): (a) the analyzer, (b) configuration of the targets, (c) signal waveform. See text for details

## 2.9 The neutral-gas mass spectrometer (ING)

The neutral-gas mass spectrometer measures: (i) the distribution of the main constituents of the cometary atmosphere (H2O, CO and CO2) and their dissociation products (O, OH, C); (ii) the distribution of the secondary constituents, such as CH4, NH3, HCN and C2H2, and their associated daughter molecules, and (iii) the isotopic ratios 13C/12C and D/H.

The instrument is mounted on a platform which can be rotated 120deg in the ecliptic plane and which includes two detection units. The main unit uses a field ionization source (FIS), which consists of 40 needles with a tip curvature radius of less than 1 micro m, held at a positive potential of 50 kV (Fig. 9a). The molecules that flow in the vicinity of the tips lose one electron by field emission; the probability of multiple ionization is negligible. All ions leave the needles with approximately the same energy, are accelerated, and pass through a carbon foil, which has a density of less than 1 micro g/cm**2. The electrons released from the foil are deflected towards a microchannel plate and initiate a pulse which indicates the start of the time taken by each successive ion to travel a distance s=10 cm, at the end of which a second pulse is generated by another microchannel plate.  The mass of the ion m is given by 2(E-delta E)tau**2/s**2, where tau is the time of flight, E is the energy after accelera-ion and delta E is the energy lost in the first impact; delta E increases with m and the resolution is consequently reduced for large masses.

This technique presents the remarkable advantage that the molecules are ionized without impact and are not disintegrated, but its main drawback is that it cannot differentiate the cometary neutrals from the gas evaporated from the spacecraft itself.

This deficiency is palliated by the adjunction of a second detection device (Fig. 9b) in which the molecules are ionized with an Electron Impact Source (EIS). The ions are then deflected from their original direction by an electric field; it is therefore possible to limit the access of the detector to ions with a velocity of about 78 km/s and to deflect slow particles with a retarding grid. The fast ions reach an electrostatic analyzer with a field configuration which deflects these particles towards a Micro-Channel Plate (MCP). The position of the impact, which yields the mass, is measured with a resistive anode mounted on the back of the MCP.

It is possible to differentiate the cometary atmosphere from the spacecraft environment by alternating the operation of the two detectors. The characteristics of the two devices are compared in Table 10.

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Table 9. Dust Mass Spectrometer characteristics

| | |
|---|---|
| Target material | Silver |
| Total drift length | 1 m |

| | |
|---|---|
| Time of flight | 4 micro s (H+) - 40 micro s (Ag+) |
| Ion detector | Secondary electron multiplier |
| Dust mass range | 3x10**-16 - 5x10**-10 g |
| Atomic mass range | 1-110 amu |
| Mass resolution, m/delta m, at m = 107 | 200 |
| Chemical composition accuracy per spectrum | 10% |
| Maximum data acquisition rate | 12 spectra/s |
| Expected number of events | 10**3-10**4 impacts during flyby |

Table 10. Neutral-Gas Mass Spectrometer characteristics

| System | FIS | EIS |
|---|---|---|
| Ionisation mechanism | Field emission | Electron collision |
| Ionisation efficiency | 10**-10 | 10**-6 |
| Mass range, amu | 1-60 | 1-28 |
| Mass resolution, amu | 1-20: 0.2<br>21-60: 1 | 0.2 |
| Intgration time (high/low bit rates) | 1 s/1 h | 1 s/1 h |

Figure 9. The two detection devices of the
neutral-gas mass spectrometer (ING):
(a) field ionization detector,
(b) electron ionization detector

## 2.10 The plasma energy analyzer (PM-1)

The plasma energy analyzer monitors the change in the solar-wind parameters as the spacecraft approaches the comet, searches for the bow shock and the contact surface, and measures the density and chemical composition of the ion population.

The instrument includes six detectors: two ion analyzers, one electron analyzer, two collectors which measure the integral plasma ion flux, and one sensor which monitors the integral electron current produced from its surface by photon and particle bombardment.

The ion detectors (Fig. 10a) are designed for the study of the energy distribution of the solar and cometary particles, and not for the investigation of their three-dimensional velocity distribution. Each sensor consists of a quadripolar electrical lens (2), a hemispherical plate analyzer (3) and a channeltron (4). The energy spectrum is swept once per second by stepping the bias voltage U(A) applied between the plates. The detector oriented towards the Sun has a conical of view (1) with a half angle of 15deg, wide enough to detect the solar wind both upstream and downstream of the cometary bow shock.

The ion detector oriented along the spacecraft-comet velocity vector is intended for operation in the innermost part of the coma, where the cometary ions are expected to have thermal velocities that are negligible with respect to their relative drift velocity of 78 km/s. This system can therefore be used as a mass spectrometer in the range 1-110 amu with a resolution m/delta m = 20; the minimum measurable ion density is 10**-3/cm**3.

The electron analyzer (Fig. 1Ob) has an aperture of 0.03 cm**2, an angular resolution of +/-2.5deg, and an energy resolution of +/-5%; its geometrical factor is 10**-5 E (keV) (cm**2.sr.keV). Its aperture is oriented perpendicular to the Sun and relative-velocity directions in order to eliminate interferences generated by photon and particle impacts. The energy spectrum is scanned by applying a series of logarithmically distributed voltage steps U(A) to a cylindrical deflection unit (1). The entrance of the instrument is controlled by a collimator (2) and a grid (3); the detector is a channeltron (4).

The integral detector which measures the solar-wind ions (Fig. 10c) consists of a collimator, a number of grids to limit the flux of photoelectrons, and a collector. A potential of +3500 V is periodically applied to one of the grids in order to stop the ion flux and evaluate the interference background. The aperture has an area of 5 cm**2 and the dynamic range of the measurements extends from +/- 10**-11 A to +/- 3x10**-9 A.

The integral detector, which is aligned with the relative-velocity vector (Fig. 10d), has similar features, but the electrodes are configured such that the incoming dust particles and neutral molecules can only impact on the first diaphragm and on the collector. By biasing the electrodes differently, in an alternative configuration, it is possible to discriminate between the cometary ions and the charged particles produced by various impact ionization processes.

The impact plasma monitor (Fig. 10e) is a gold electrode, biased at a fixed potential of -17 V, which measures the integral flux of electrons emitted by the impact of neutral gas, dust particles and photons, in the range 10**-10-3x10**-5 A.

The characteristics of the various detectors are summarized in Table 11.

Table 11. Plasma Energy Analyser characteristics

| Particles | Solar ions | Cometary ions | Electrons | Solar ions | Cometa |
|---|---|---|---|---|---|
| Pointing direction | Sun | Relative velocity | Perpendicular to Sun and relative velocity | Sun | Relati veloci |
| Energy range | 50 eV-3.5 keV | 15 eV-3.5 keV | 3 eV-10 keV<br>3 eV-30 eV | Integral | Integr |
| Points per specttum | 60 | 120 | 30 | 1 | 1 |
| Time resolution | 1 s | 1 s | 1 s | 0.125 s | 0.125 |
| Aterture | 15deg half cone | 15deg half cone | 5deg X 10deg | 45deg half cone | 8deg h |
| Detector | Channeltron | Channeltron | Channeltron | Electrode | Electr |

Figure 10. The detectors of the plasma energy analyzer (PM-1):
(a) ion spectrometer, (b) electron spectrometer,
(c) solar ion integral detector, (d) cometary ion integral detector, (e) impact plasma monitor.
See text for details

### 2.11 The energetic-particle analyzer (TN-M)

The prime objective of the energetic-particle analyzer is to measure the energy and flux of the cometary ions that might be accelerated by, for example, solar-wind magnetic fields.

Two similar telescopes provide information about the angular distribution of the ion flux; one is oriented at right angles to the magnetic field, in the ecliptic plane; the other detector looks in the same plane, in a direction at 35deg to the first telescope and approximately opposite to the spacecraft velocity vector.

Each telescope consists of two silicium detectors, A (8 mm in diameter and 0.1 mm thick) and B (16 mm in diameter and 1 mm thick), and an anti-coincidence scintillation shield (Fig. 11). Electrons with energies of less than 0.2 MeV are deflected away from the entrance aperture by a magnet. The low-energy (30-640 keV) ions trigger a signal in detector A only. More energetic particles are detected in both A and B, and it is possible to distinguish between electrons, protons and heavier nuclei by comparing the amplitudes of the signals delivered by the two detectors.

The characteristic parameters of these two telescopes are given in Table 12.

Figure 11. The telescope of the energetic-particle analyzer (TN-M)

### 2.12 The magnetometer (MISCHA)

The prime objective of the magnetometer experiment is to determine the role of the magnetic field in the interaction between the solar wind and the comet and to identify the characteristic boundaries of the cometary environment (bow shock, contact surface, etc.).

The sensors of the MISCHA magnetometer (Fig. 12,) are mounted on a boom, which can be seen on the lower edge of the right-hand solar panel in Figure 15. A single-axis sensor and a triaxial sensor are mounted 1 and 2 m, respectively, from the edge of the solar panel. The advantage of this dual-sensor fluxgate system is the possibility to determine the spacecraft’s stray magnetic field. The basic features of this instrument are summarized in Table 13.

## 2.13 The plasma-wave and ion-trap experiment (APV-N)

The main objectives of the APV-N experiment are: (i) to investigate collective plasma processes and fine structures in the zone of interaction between the comet and the solar wind, (ii) to detect the anomalous ionization of the cometary atmosphere by the solar wind and identify the mechanism of this phenomenon, and (iii) to measure the spectra of the electromagnetic and electrostatic instabilities in the solar wind and cometary ionosphere and to search for the bow shock and contact surface.

Figure 12. The two-sensor system and the
electronics box of the magnetic-field
experiment (MISCHA)

Table 12. Energetic-Particle Analyser characteristics

| | |
|---|---|
| Ion energy range (detector A) | |
| Resolution | 20 keV-640 keV |
| - range 20-160 keV | 10 keV |
| - range 160-400 keV | 20 keV |
| - range 400-640 keV | 40 keV |
| Energy ranges (detectors A and B) | |
| - electrons | 0.5-0.75 MeV |
| - protons | 3.2-13 MeV |
| - ions (Z >= 2) | 3.2-13 MeV/nucleon |
| Integral flux of protons and nuclei | Energy >= 13 MeV/nucleon |
| Geometrical factor | 0.2 cm**2 sr |
| Field of view | 25deg half cone |
| Time resolution | 4 s (encounter); 10 or 20 min (cruise) |

Table 13. Magnetometer characteristics

| | |
|---|---|
| Dynamic range | +/- 100 nT |
| Resolution | 0.05 nT |
| Noise level | 0.01 nT Hz**-1/2 |
| Zero drift | +/- nT/month |
| Bandwidth | 10 Hz |
| Time resolution | 10 vector/s |
| (high-speed telemetry) | 1 spectrum/25 s |
| Number of frequency points | 128/spectrum |

The experiment consists of two sensors, one dipole made of two meshed spheres with integral pre-amplifiers and a Faraday cup, and an electronics box (Fig. 13). The dipole detects electric fields and the Faraday cup measures ion-flux fluctuations with frequencies of up to 1 kHz. The electric sensors are mounted on a Y-shaped 5 m long boom and the Faraday cup is located on the spacecraft body (Fig. 14).

The main parameters of the APV-N experiment are given in Table 14.

## 2.14 The electric-field and Langmuir-probes experiment (APV-V)

The primary objectives of the plasma and wave measurements performed by APV-V are: (i) to measure the density of the solar wind just before it is influenced by cometary constituents, thereby establishing a reference for understanding the subsequent solar. wind-comet interaction, (ii) to observe the mass loading of the solar wind by cometary ions, either directly or through the associated wave instabilities, (iii) to obtain plasma-density and temperature profiles, as well as wave-frequency spectra during the cometary transit, and (iv) to search for the signatures of collision-free shocks and contact surface.

The sensors are mounted on two symmetrical stubs attached to the outer solar panels (Fig. 15). Two spheres, 10 cm in diameter (Fig. 14a) and separated by 11 m, form a dipole for measuring electric fields. The Langmuir probes are fixed at mid length; they are cylindrical and their collecting area is 4.4 cm**2; they are oriented in such a way that their symmetry axis is parallel to the gas-flow velocity vector during the flyby; conical elements fixed at their tips protect them from the direct impact of cornetary gas and dust particles (Fig. 14b).

The main characteristics of the APV-V instrument can be found in Table 15.

---

Table 14. Plasma-Wave and Ion-Trap Experiment characteristics

| | |
|---|---|
| Electrical antenna | |
| Base line | 2m |
| Frequency range | 0.01-1000 Hz |
| Sensitivity | 1 micro V/Hz**1/2 at 1kHz |
| Dynamic range | 60 dB |
| | |
| Faraday cup | |
| Collector area | 5 cm**2 |
| Frequency range | 0.01-1000 Hz |
| Sensitivity | 10**-3 A/cm**2 at 25 Hz |
| Dynamic range | 60 dB |
| | |
| Data analysis (for both instruments) | |
| Signal waveform | 10**-2 - 10**2 Hz |
| Spectral analysis in range 10-1000 Hz | 10 frequency points/s |
| Passband filters (10-100 Hz and 100-1000 Hz) | 1 sample/s |

---

Table 15. Electric-Field and Langmuir-Probe Experiment characteristics

| | |
|---|---|
| Electrical antenna | |
| Base line | 11m |
| Frequency range | 0-300 kHz |
| Sensitivity | 3 micro V/m Hz**1/2 at 1 kHz |
| Dynamic range | 70 dB |
| Waveform analysis | 0-8 Hz |
| Passband filters in range 8 Hz - 300 kHz | 16 filters |
| | |
| Langmuir probes (two units) | |
| Collector area | 4.4cm**2 |
| Frequency range and waveform analysis | 0-4 Hz |
| Sensitivity | 2x10**-12 A/cm**2 |
| Dynamic range | 60 dB |

---

Figure 13. The plasma-wave and ion-flux experiment (APV-N): electronic box (back left), ion trap (back right) and meshed spheres (front)

Figure 14. The sensors of the electric field and Langmuir probe experiment (APV-V): (a) electric-field sensor, (b) Langmuir probe with its protective cone

## 3. The spacecraft

The Vega spacecraft was composed of a Halley flyby probe and a Venus descent module; the whole system weighed about 4.5 t. The Halley probe is shown in Figure 15 in its nominal flyby configuration: the orientation of the vehicle velocity relative to the comet is also indicated. The spacecraft has a wingspan of the order of 10 m, and it carries 120 kg of scientific instrumentation. On its trajectory to Venus, the probe was still surmounted by the descent module (not shown in Fig. 15), which was a spherical object with a diameter of 2.5 m and a mass of approximately 2 t. The Vega vehicle is derived from the Venera series of spacecraft. A number of modifications improve the reliability of the probe; for example, 5 m**2 of shield have been added in order to protect the most essential subsystems against the bombardment of dust particles with masses of less than 0.1 g. A dual-sheet bumper shield has been adopted; it is composed of a thin metallic front sheet (0.4 mm) and a thicker rear sheet, separated by several centimetres.

Figure 15. The Vega spacecraft in cometary flyby configuration after release of the Venus lander. The orientation of the relative velocity vector (’relative’ in the comet frame of reference) is defined by its projections in the XY- and ZY-planes of the spacecraft coordinate system

The spacecraft structure resembles a cylindrical body connected to two conical skirts. The lower skirt houses a motor for orbital manoeuvres and a toroidal pressurized utility instrument bay; the cylindrical compartment contains the fuel tanks and the upper skirt is the interface that held the Venus lander. Two pairs of deployable solar panels are mounted on each side of the cylindrical section: the solar array has a total area of nearly 10 m**2. The spacecraft is three-axis-stabilized during the cometary flyby by a gyroscopic system and a number of gas nozzles, most of which are mounted on the solar panels.

The telemetry system consists of a high-data-rate channel (BRL) and a low-data-rate channel (BTM). The BRL channel is used for real-time transmission only. Its capacity of 65536 bit/s can be reduced by half if required by propagation conditions; that of the BTM channel is 3072 bit/s. The scientific data can also be stored by onboard magnetic tape recorders (capacity 5 Mbit) and subsequently telemetered through the BTM channel, once every 20 days during the interplanetary transit and once every 20 min around the time of cometary flyby. The high-gain antenna must be directed towards the Earth whenever data are transmitted via the BRL channel.

The scientific instruments can be classified into three categories, characterized by common objectives:

(i) The electromagnetic field sensors (MISCHA, APV-N and APV-V) are mounted on booms, as far as possible from the spacecraft to achieve the best degree of electromagnetic cleanliness.
(ii) The dust, gas and plasma detectors have pointing directions generally related to the spacecraft velocity relative to the comet.
(iii) The optical systems that observe the nucleus (TVS, IKS, TKS) are located on the automatic pointing platform.

The platform is shown in Figure 16; it has a mass of 82 kg and carries 64 kg of instrumentation. It can scan an angular sector of 110deg in the ecliptic plane, and 60deg in a plane perpendicular to the ecliptic.

Figure 16. General view of the pointing platform without thermal blanket

## 4. The Mission

The Vega spacecraft were launched from the Tyuratam pad area of the Baykonour Cosmodrome by two three-stage Proton rockets fitted with six strap-on boosters. The space vehicles were injected into their trajectories towards Venus before completing their first revolution around the Earth (Fig. 17a).

During most of the transit towards Venus, the solar panels were oriented towards the Sun. The spacecraft's attitudes were not otherwise controlled, except during possible periods of a few hours when three-axis-stabilization was required for high-bit-rate data transmission. Orbital corrections were performed during the first two weeks after launch and was repeated during the last two weeks before arrival in the environment of Venus.

Three further orbital manoeuvres were foreseen on the second leg of the journey to Comet Halley: the first, two to four weeks (Fig. 17b) after the Venus flyby, the second midway between the planet and the comet, and the last two to four weeks before the Halley flyby. Once the last manoeuvre has been performed, the pointing platform will be oriented and the camera can then take its first look at the comet.

Fig- 17. The paths of the Vega probes (a) from Earth to Venus, and (b) from Venus to Halley. The projection of the inner portion of the trajectory of Halley on the plane of the ecliptic is a1so shown. The Comet and the Earth are orbiting in planes that intersect at an angle of 18deg. The nodes are the points where Halley's orbit intersects the ecliptic

All experiments are to be switched on two days before closest approach. The direct high-speed telemetry will be transmitted from -48 h to -45 h at a cometary distance of 14x10**6 km, from -24 h to -22 h at a cometary distance of 7 x 10**6 km and from -2 h to + 1 h during the cometary flyby. Two other high-speed telemetry transmission sequences are also foreseen, one and two days after flyby. A limited amount of data can also be stored and transferred every 20 min to the onboard tape recorder, in order to cover the 22 h gaps when the high-speed telemetry is switched off (Table 1).

A number of other telemetry modes are available. They are being used for, for example, transmitting low-bit-rate information from a number of selected experiments during the interplanetary cruise.

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