1. ***MEA Scientific Objectives***

The encounters of Mariner 10 with the planet Mercury showed that the planet interacts with the solar wind to form a bow shock and a possibly permanent magnetosphere. The observations provide a first indication of the dimensions of the magnetosphere, which appears to be similar in shape to that of the Earth but much smaller in relation to the size of Mercury and to its magnetic moment. Electron populations resembling to those found in the Earth’s magnetotail, within the plasma sheet and adjacent regions, were observed at Mercury; the magnetosphere of the planet resembling to a reduced version of that of the Earth. However, only partial electron measurements were made onboard Mariner 10 as the protective cover of the sunward-facing electrostatic analyzers (ESAs) did not open fully after launch. The MESSENGER mission, which was the first one to orbit the planet, does not have a low energy electron spectrometer onboard. The low-energy plasma measurements that will be performed on the fast spinning MMO spacecraft of the BepiColombo mission thus appear to be necessary to allow a thorough study of the plasma processes inside the magnetosphere of Mercury, a weakly magnetized planet without a conducting ionosphere.

The MEA instrument is made of two sensors combining the selection of incoming electrons according to their energy by electrostatic deflection in symmetrical toroidal analyzers (ESA) having a uniform angle energy response with a fast imaging particle detection system. This particle imaging is accomplished by microchannel plate (MCP) electron multipliers and position encoding by discrete anodes. Each sensor has a 360deg. Field of view (8deg. field of view in a plane parallel to the satellite spin axis). The sensors are located at corners of the octagonal satellite; the two sensor view planes being perpendicular, the time resolution to obtain a three-dimensional distribution function of electrons between 3 and 25,500 eV is thus 1 s. Because the electron fluxes are expected to cover more than six decades within the measured energy range and to be extremely variable both in the solar wind and in the magnetosphere of the planet, an electronic device allowing varying the geometrical factor by a factor of 100 has been implemented for the first time in the top-hat ESA.

The particle and field measurements made by the Bepi Colombo magnetospheric orbiter will also allow a study of solar wind parameter regimes not accessible to direct observations elsewhere. MEA will probe the various components of the solar wind, the thermal core, the always present suprathermal halo, and the sharply magnetic field aligned ‘strahl’ which is usually anti-sunward moving. The MEA instrument has a solar wind mode where the energy range is from 3 to 3000 eV with energy resolutions varying from 7.8% to 15%. The angular resolution of the MEA detector, 22.5deg x 11.25deg, is comparable with the resolutions of Helios 1 and Helios 2 of 19deg x 30deg and 19deg x 13deg, respectively. Solar electrons from 0.1 to 102 keV, i.e. inside the energy range covered by MEA are furthermore excellent tracers of the structure and topology of the interplanetary magnetic field lines since they are fast and have very small gyroradii; they will be extensively used to study the connections between heliospheric disturbances measured in situ and coronal structures as detected by remote sensing instruments onboard dedicated solar missions like Solar Orbiter.

1. ***MEA Design***

The MEA instrument is made of two sensors (MEA1 and MEA2) combining the selection of incoming electrons according to their energy by electrostatic deflection in a symmetrical toroidal analyzer (ESA), having an angle–energy response uniform in azimuth, with a fast imaging particle detection system. This particle imaging is accomplished by microchannel plate (MCP) electron multipliers and position encoding by discrete anodes. The two MEA sensors have identical electron optic design except that the entrance aperture of one of the sensors is covered by a grid-attenuator with a transparency of 5% to reduce its geometrical factor by a factor 20. The ESA consists of a 95deg. toroidal deflector and of a spherical top section. The ratio between the inter-plate gap and the central radius of the toroidal deflector is 0.05. Such a deflector imposes at least three reflections of UV photons. The toroidal deflector consists of two concentric electrodes radius, respectively, equal to 35.88 and 34.12 mm. A 2mm gap between the toroidal inner element and the inner top sphere is located 62deg. over the horizontal plane crossing the center of the torus. The central top part of the ESA comprises two spherical electrodes, with a radius of 77.4 and 84.6 mm, respectively. The opening angle of the outer top electrode is 30deg. To keep an 8deg. entrance aperture, the spherical part of the top-hat has a diameter of 31.1 mm, and a conical element extends the top-hat up to a diameter of 47.8 mm. The grid attenuator is located at the periphery of the collimator. The entrance aperture is defined by the collimator that provides also a first UV rejection. The entire configuration has a cylindrical symmetry around the central vertical axis. The outer electrode and the top-hat are at signal ground. The two parts of the inner electrode can be put at the same voltage (Uan = Utop), in that case the analyzer behaves like a classical top-hat analyzer. The inner electrode is then biased with voltages varying from +1 to +3125V to cover the energy range in normal ESA operation (k = E/V = 9.6). On the other hand, the central part of the inner electrode (Utop) can be biased with voltages lower than those applied to the toroidal part (Uan). In that case, the analyzer accepts particles coming from slightly higher azimuth, thus avoiding the satellite surface. The energy and angular acceptance are both reduced leading to a reduction of the geometrical factor. The reduction factor reaches 100 when the R = Uan/Utop ratio reaches 5. Since dGF/dR is rather high in the case of maximal attenuation, the Uan and Utop stability is a key factor for low energy measurements. ‘‘Standard’’ HV source provides about 50mV uncertainty if the maximal voltage is about 3000 V. To reduce the GF uncertainty at the low energies, the MEA HV unit uses a special low voltage mode for energy less than 100 eV. The fact that the analyzers have complete cylindrical symmetry provides a uniform response in polar angle. A beam of parallel incident electron trajectories is focused to the grid covering the MCP. The FWHM response of an incident parallel beam on the MCP surface is 1deg. The exit position and thus the incident polar angle of the electrons are identified using the information from the anodes. The full angular range of each analyzer is divided into 16 channels of 22.5deg. each. The inherent geometric factor of a full 360deg. analyzer is 2AE/E = 0.012 cm2 sr eV/eV, neglecting grid transparencies, support posts in the collimator, and MCP efficiency. A denotes the aperture area and y the azimuth response of the analyzer. The entrance fan covers a viewing angle of 360deg. in polar and 10deg. in azimuth directions. The outer and inner plates of the toroidal deflector and the top-hat are scalloped in order to minimize the transmission of secondary electrons and to reduce UV stray light. For the same reason the analyzer plates are covered with a copper black coating. The inner spherical part of the top of analyzer is polished to reduce the heat flux into the instrument. The deflection voltage is varied in an exponential sweep made of 128 small steps. The full energy sweep with 64 contiguous energy channels is performed either 16 or 32 times per spin. Thus a partial two-dimensional cut through the distribution function in polar angle is obtained every 1/16 or 1/32 of the spacecraft spin. The full 4 electron distributions are obtained during half spin using a single analyzer and in 1/4 of a spin using the two analyzers. A special mode is foreseen where each analyzers measures electron fluxes at a constant energy, thus allowing very fast data acquisition. A chevron stack of two rings MCP is used to multiply the electrons. The anode system consists of 16 sectors anode corresponding to 16 polar sectors of analyzer, 22.5deg. each. An additional ring anode is located behind the inner 360deg. part of the MCP which cannot be directly reached by electrons passing through the analyzer. The count rate of this anode provides an estimation of the penetrating radiation background. All 17 anodes are connected to amplifiers/discriminators followed by counters. High voltage system of MEA provides two sweeping voltages and MCP power supply. The energy of the particles is selected by varying the deflection voltages of the inner plates of the ESA. The variations of these deflection voltages are synchronized with the spin period of the spacecraft. The deflector voltage levels are equally logarithmically spaced. All instrument functions are controlled by an FPGA that communicate with the common DPU of MPPE (MDP1).

Specifications of MEA

|  |  |
| --- | --- |
| Field of view | 8deg. X 360deg. |
| Angular resolution | 22.5deg x 11.25deg |
| Energy range | 3eV–25,500 eV (Mercury mode) 3eV- 3000 eV (solar wind mode) |
| Energy resolution | E/E~10% (at full G-factor) |
| Time resolution—three-dimensional | 2 s (using a single analyzer)  1 s (using the two analyzers) |
| G-factor (cm2 sr eV/eV)  (8deg. X 360deg.) | MEA1: 1.2 X 10-2 – 1.2 X 10-4  MEA2: 0.6 X 10-3 – 0.6 X 10-5 |

1. ***MEA Operations***

After Mercury orbit insertion, MEA continues observation during all the orbital phases except the period that MEA should be turned off due to the thermal / power requirement. MEA is part of the MPPE consortium and will obey the MMO instrument suites operation. The two sensors heads are transmitting the raw counts values to the Mission Data Processor (MDP) through the RMAP Spacewire interface. MEA will have versatile and easily programmable operating modes and data processing routines to optimize the data collection for specific scientific studies and widely varying plasma regimes. MEA data products are :

1. Engineering packet which contains the current technical information of the instrument.
2. Electron distribution parameters. The instrument transmit temperature (T1,2,3), heat flux vector (Q1,2,3), and number density (N1,2,3) calculated in the 3 energy bands. Position of the boundaries of each energy band is defined by command.
3. Electron pitch angle distribution (instrument needs magnetic field vector as external input for this mode). Instrument transmits 2-D angle-energy distribution.
4. Full 3-d Electron distribution. The instrument transmits a complete angular-energy spectrum accumulated for 1/4 of the spacecraft spin at least.

Data sent from MEA to MDP

|  |  |  |  |
| --- | --- | --- | --- |
| Mode | Produced Data | Raw data rate | Remarks |
| (DATA MODE 2) | <count data>  16 channels x 16 sectors x 32 energies | 32768bps | 16 bits/data |
| (DATA MODE 4) | <count data>  16 channels x 16 sectors x 64 energies | 65536bps | 16 bits/data |

\*1 Sensitivity of about 120degrees (polar) is reduced down to 1/10 with mechanical attenuation grid.

\*2 Sensitivity of about 120degrees (polar) is reduced down to 1/10 with mechanical attenuation grid.

1. ***MEA Data Products***

Following table shows MPPE data mode name and corresponding data products of MEA1 and MEA2. Data mode used is Mode 2.

|  |  |  |  |
| --- | --- | --- | --- |
| **MPPE MODE NAME** | **L mode data products** | **M mode data products** | **H mode data products** |
| 1. Default Observation Mode | MEA1  Et-OMN(4s)  Et-PAP(16s)  VM(16s)  3D-LL(640s) | MEA1  Et-OMNm(4s)  Et-PAP(4s)  VM(4s)  3D-M(8s)  or  3D-M(4s) | N.A. |
| MEA2  Et-OMN(4s)  Et-PAP(16s)  VM(16s) | MEA2  Et-OMNm(2s)  Et-PAP(2s)  VM(2s) |
| 2. Exospheric Mode | MEA1  Et-OMN(4s)  Et-PAP(16s)  VM(16s)  3D-LL(640s)  MEA2  Et-OMN(4s)  Et-PAP(16s)  VM(16s) | MEA1  Et-OMNm(4s)  Et-PAP(4s)  VM(4s)  3D-M(8s)  or  3D-M(4s)  MEA2  Et-OMN(2s)  Et-PAP(2s)  VM(2s) | MEA1  3D-H(4s)  MEA2  3D-H(2s) |
| 3. Solar Wind Mode/IP Shock Local Mode |
| 4. IP Shock Macro Mode / Bow Shock Mode |
| 5. Reconnection Mode |
| 6. Magnetospheric Mode1 / Mode2 / Mode3 |

The detailed description of MEA data products are shown in the following table.

[L mode]

MEA1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Data Product Name** | **Description** | | **Time Resolution (sec)** | **Note** |
| Et-OMN | E-t count data | 16 energy | 4 |  |
| Et-PAP | E-t pitch angle data | 4 energy x 16 pitch angle | 16 |  |
| VM | Velocity Moment | n(density)  nVx, nVy, nVz (Velocity)  Pxx, Pyy, Pzz, Pxy, Pyz, Pzx (Pressure)  qx, qy, qz (heat flux) | 16 | 6 energy ranges  0: all energy steps above satellite potential \* 2;  1-5: 5 energy steps below satellite potential \* 2 |
| 3D-LL | 3D count data | 88 direction  X 16 energy | 640 |  |

MEA2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Data Product Name** | **Description** | | **Time Resolution (sec)** | **Note** |
| Et-OMN | E-t count data | 16 energy | 4 |  |
| Et-PAP | E-t pitch angle data | 4 energy x 16 pitch angle | 16 |  |
| VM | Velocity Moment | n(density)  nVx, nVy, nVz (Velocity)  Pxx, Pyy, Pzz, Pxy, Pyz, Pzx (Pressure)  qx, qy, qz (heat flux) | 16 | 6 energy ranges  0: all energy steps above satellite potential \* 2;  1-5: 5 energy steps below satellite potential \* 2 |

[M mode]

MEA1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Data Product Name** | **Description** | | **Time Resolution (sec)** | **Note** |
| Et-OMNm | E-t count data | 32 energy | 4 |  |
| Et-PAP | E-t pitch angle data | 4 energy x 16 pitch angle | 4 | 4 starting energy steps and width are selectable by commanding |
| VM | Velocity Moment | n(density)  nVx, nVy, nVz (Velocity)  Pxx, Pyy, Pzz, Pxy, Pyz, Pzx (Pressure)  qx, qy, qz (heat flux) | 4 | 6 energy ranges  0: all energy steps above satellite potential \* 2;  1-5: 5 energy steps below satellite potential \* 2 |
| 3D-M(8s) | 3D count data | 88 direction  X 16 energy | 8 | S0 S1 S2 S3 S5 |
| 3D-M(4s) | 3D count data | 88 direction  X 16 energy | 4 | S4 S6 S7 S8 |

MEA2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Data Product Name** | **Description** | | **Time Resolution (sec)** | **Note** |
| Et-OMNm | E-t count data | 32 energy | 2 |  |
| Et-PAP | E-t pitch angle data | 4 energy x 16 pitch angle | 2 |  |
| VM | Velocity Moment | n(density)  nVx, nVy, nVz (Velocity)  Pxx, Pyy, Pzz, Pxy, Pyz, Pzx (Pressure)  qx, qy, qz (heat flux) | 2 | 6 energy ranges  0: all energy steps above satellite potential \* 2;  1-5: 5 energy steps below satellite potential \* 2 |

[H mode]

MEA1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Data Product Name** | **Description** | | **Time Resolution (sec)** | **Note** |
| 3D-H | 3D count data | 88 direction  X 32 energy | 4 | 16 sectors, 8 channels |

MEA2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Data Product Name** | **Description** | | **Time Resolution (sec)** | **Note** |
| 3D-H | 3D count data | 88 direction  X 32 energy x 2 | 2 | 16 sectors, 8 channels +  16 sectors, 8 channels |