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DEVICE DETECTING NEUTRAL SOLAR WIND AND LABORATORY TESTS

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The GAS-2 was designed to detect neutral atoms of the solar wind with typical energies of about 1 keV. The coincidence technique separates fast atoms from the intense flux of photons from the Sun. The energy of detected hydrogen atoms is estimated using the time-of-flight method. The device was built for the RELIKT-2 spacecraft and was laboratory tested.

Researchers have so far accumulated a lot of data indicating that interplanetary space contains fluxes of neutral atoms from various sources which carry information about the physics of the Solar system and its neighborhood (see the review of papers in [1]). These fluxes include hydrogen and helium atoms entering the Solar system as it moves with respect to the local interstellar gas at $V \approx 20$ km/sec, neutral fluxes of the solar wind, high-energy neutral atoms from the magnetospheres of the Earth and other planets, fluxes of neutral gas from cometary nuclei, etc.

Until recently it was impossible to detect neutral particles directly (in situ), and only the integral neutral gas density in an observation direction could be derived from optical and radio data. Fluxes of neutral gas (helium) were first measured directly in interplanetary space only by the GAS experiment [2] aboard the ULYSSES spacecraft. However the techniques used in this experiment did not detect hydrogen, which is the main component of the interplanetary neutral gas, nor could they analyze the energy spectrum of the detected atoms. None of the existing experimental techniques so far used have yielded the content of neutral hydrogen in the solar wind, and it has only been estimated theoretically.

The advent of compact time-of-flight devices made it feasible to measure the intensity and energy of neutral fluxes in space experiments, and the GAS-2 experiment [3] was planned to study neutral hydrogen atoms of the solar wind with a typical energy of about 1 keV. This paper describes the device and reports on laboratory tests of the model designed for the RELIKT-2 spacecraft, which is to be launched in 1997 and placed in the Lagrange liblation point L_2.

Detecting neutral hydrogen atoms in the solar wind is complicated by the presence of intense fluxes of photons from the Sun. Some estimates indicate that its intensity is several orders of magnitude higher than that of the solar wind [4]. Fast neutral particles with an energy of about 1 keV may be detected, in principle, by secondary-electron multipliers. The most convenient devices are channel electron multipliers, such as microchannel plates (MCP), and an assembly of two VÉU-7 MCPs was used. In the presence of an intense light flux, which also generates secondary electrons, these devices alone cannot directly detect neutral atoms.

In order to overcome this difficulty, Gruntman and Morozov [5] proposed detecting coincidences of photons and particles on one side and secondary electrons emitted from a thin foil by photons and particles on the other side.

The GAS-2 device uses coincidences between electrons from the foil and particles detected by MCP detectors. A diagram of the device is given in Fig. 1 (vacuum section III). It includes a solar blind 1 with a SmCo permanent magnet 2 generating a magnetic induction of about 0.15 T in a 3-cm region on the blind axis for deflecting charged particles. A thin carbon foil 3 (about 100 Å thick supported by a grid

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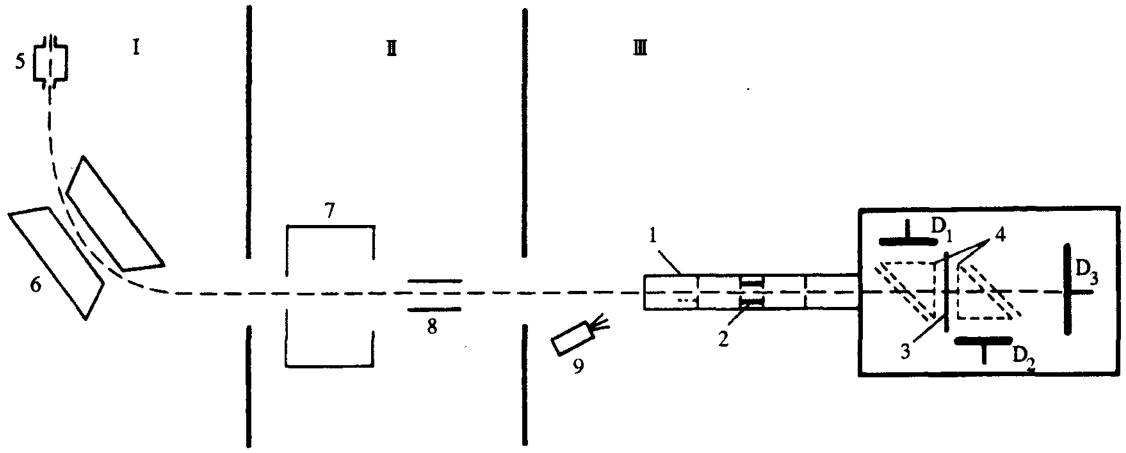

Fig. 1. Diagram of the GAS-2 device and its test vacuum facility.

from 5-μm wire with a mesh width of 30 μm) is used for secondary-electron emission by neutral particles. Two electrostatic mirrors 4 steer electrons emitted from the foil to detectors D_1 and D_2. A detector D_3 detects fast particles and photons passing across the foil. The solar blind placed upstream of the device attenuates the flux of photons by a factor of more than 10^7 [6].

The device axis is aligned at ~ 10° to the line of the Sun. This orientation was selected to obtain an optimal signal-to-noise ratio (the ratio is maximum when the device axis is at 7–8° [4] to the direction of the Sun) and to avoid exposure to direct solar light when the spacecraft's orientation is changed once every five to seven days.

Fast neutral particles and photons passing across the blind hit an 80–100-Å carbon foil. A photon may either emit an electron from the upstream surface of the foil and be detected by D_1 (back-scattering geometry), or emit an electron from the downstream surface and be detected by D_2 (transmission geometry), or pass through the foil without emitting an electron and be detected by D_3.

A fast particle may also generate an electron and be detected in either back-scattering or transmission geometry, but, in contrast to a photon, it may be simultaneously detected by D_3. If the device only detects coincidences between D_1 and D_3, or D_2 and D_3 signals (within a preselected time interval of ~ 500 nsec), signals due to fast neutral particles can be separated from those due to photons. Generally speaking, photons can generate D_1–D_3 or D_2–D_3 coincidences only when two photons are consecutively detected within a time interval of ~ 500 nsec.

Besides, the device can evaluate the energy of a heavy particle provided that its mass is known by measuring the time of flight over the base distance (6 cm) between the start detector (thin foil) and the stop detector (D_3). The start signal is taken from D_1 or D_2, depending on which detected an electron emitted from the foil (taking into account the transit time between the foil and detector). The stop signal is generated in D_3 by a heavy particle. The time of flight of each particle is digitized and defines the number of the counting channel in the data storage in which the stored number is incremented. Given sufficient detected events, the device yields a time-of-flight spectrum, which can be easily converted to an energy spectrum. The device can also analyze triple coincidences when a heavy particle generates both back-scattered and transmitted electrons, and is detected in D_3. This technique improves the suppression of the photon background. Count rates of each detector are also recorded.

Each detector is supplied from separate power sources, whose output voltages may be 0, 2, 2.2, or 2.4 kV, depending on the command sent to the device. In order to protect the detectors from overload, the voltage across a detector is stepped down to zero, if its count rate is higher than the limiting level of 10^5 pulses/sec.

In laboratory tests, the device is driven by a ground support equipment (GSE) based on a PC/AT personal computer with dedicated interfaces [7]. The

GSE powers electric circuits of the device and sends it operation commands. The software package was written in Pascal and defined voltages across the detectors D_1–D_3, the accumulation times of time-of-flight spectra, and generated the commands for testing the device operation. The data transmitted from the device can be written to the hard disk, converted to energy spectra, displayed on the monitor, and printed.

The device was tested on the vacuum facility, whose diagram is given in Fig. 1. It includes an ion source 5, mass separating magnet 6, charge-exchange chamber 7, detecting capacitor 8, and a UV lamp. All these components are placed in three vacuum sections I–III with separate pumps. The ion beam generated by the ion source is accelerated to the required energy and passed across the magnet 6 to separate ions of a given mass. Then the beam is directed to the charge-exchange chamber where a fraction of ions are neutralized. They are neutralized by the resonant or quasiresonant reaction so that their energy should not change (charge exchange takes place at large impact parameters). Ions which are not neutralized are removed from the beam by the deflecting capacitor 8. The hydrogen UV lamp acts as a source of photons.

The measurements were performed both with and without the solar blind. Ion beams could be detected without the blind. The efficiency of the permanent magnet in terms of elimination of fast charged particles was also tested. We found that H^{2+} and He^+ ions with energies of up to 4 keV (maximum ion energy in these experiments) do not pass into the device. We have tested the detection of H_2, He, H_2^+, and He^+ beams with energies of 1 to 4 keV.

Figure 2 shows the time-of-flight spectrum of hydrogen molecules with an energy of 4 keV. The distribution maximum corresponds to an energy of $\sim$ 3.5 keV. The spectrum is shifted because of the energy loss in the foil. Similar spectra were recorded with other atoms, molecules, and ions.

The detection probability of neutral particles by D_3 was determined by measuring the absolute particle count rates [5]. The technique uses the fact that one particle entering the device may generate two (in this case even three) signals, which are detected independently. In this case, the detected events are the emission of an electron from the foil (in the backscattering or transmission geometry) and the arrival of the particle itself. If I_0 is the measured flux of neutral particles, and P_2 and P_3 are the probabilities of detecting the first and second event, then the count rates of the detectors D_2 and D_3 are $I_2 = P_2 I_0$ and $I_3 = P_3 I_0$, and the frequency of coincidences, i.e., simultaneous signals from the two detectors D_2 and D_3, is $I_{23} = P_2 P_3 I_0$. These three equations determine $I_0 = I_2 I_3 / I_{23}$ and $P_3 = I_{23} I_2$. We found that $P_3 \approx 0.02$ for He and H_2 beams with an energy of 3 keV. The probability P_3 is so small because the atoms and molecules are strongly scattered by the foil, and the detector D_3 detects only a fraction of the beam I_0.

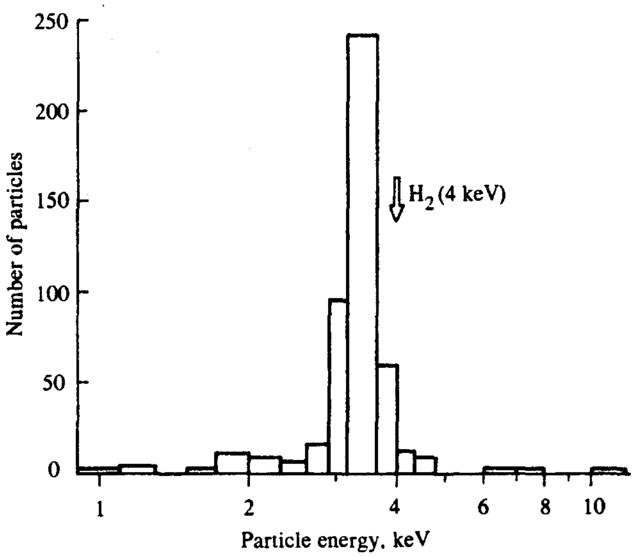

Fig. 2. Time-of-flight spectrum of hydrogen molecules with an initial energy of 4 keV downstream of a carbon foil.

Similarly the flux I_0 can be derived from measurements by the detectors D_1 and D_3 and their coincidences $I_0 = I_1 I_3 / I_{13}$ in order to obtain more reliable data.

The device was also tested with ultraviolet radiation. The flux of photons was estimated from the parameters of the lamp and the geometry of the experiment, and also from the count rate of electrons emitted from the carbon foil by Lyman α-photons [8]. It turned out that the spectrum of atoms is efficiently measured using double coincidences at a ratio of the number of photons to that of neutral particles of (5–7)$\cdot 10^4$. In this case the absolute densities of neutral fluxes ranging between 10^2 cm^{-2} and 10^4 cm^{-2} can be detected.

At a very high photon flux, an additional peak is recorded on the energy spectrum (this peak was also observed at a low photon flux, but after a very long exposure). We concluded that the peak is due to the ionization of residual gas molecules in the device (the vacuum in chamber III was $\sim 5 \cdot 10^{-6}$ torr, and in the device the pressure was slightly higher). Since the vacuum in space will be deeper, we expect that this additional peak will be considerably smaller. Besides, we expect that in space the flux of photons will be significantly attenuated by the solar blind.

The overall dimensions of the GAS-2 device are 200 × 200 × 200 mm, and it masses 4.5 kg. The power consumption is 3 W. The blind length is 900 mm, and masses 1.8 kg. Data will be accumulated on-board and transmitted to the flight control center.

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