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GAS 2 Instrument for Neutral Solar Wind Detecting

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Abstract. The GAS 2 instrument is designed to detect neutral atoms (especially H) of the solar wind with typical energies of about 1 keV. To separate fast atoms from intense flux of photons from the sun the coincidence technique was used. The instrument was tested and calibrated and it was shown that GAS 2 could really measure various kinds of light neutral atoms and ions in keV energy range in the presence of ultraviolet radiation.

1 Introduction

It is well known 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, e.g., reviews in the Proceedings of the First ISSI Workshop ed. by Von Steiger et al. (1996)). The fluxes include: hydrogen and helium atoms entering the Solar system due to their motion relatively to the local interstellar gas with the velocity of 20 km/s; neutral fluxes of the solar wind; high energy neutral atoms from the magnetosphere of the Earth and planets; the fluxes of neutral gas from cometary nuclei, etc. Neutral atoms are not sensitive to electric or magnetic fields and move along straight lines while traveling through the space. The only distortions of their trajectory result from well-known gravitational fields and this effect can be quite easily calculated. That is why the fluxes of neutral particles are so promising to be an instrument for remote sensing of distant plasma.

So far only GAS experiment (Rosenbauer et al. 1983, Witte et al. 1993) aboard the Ulysses spacecraft managed to measure directly the fluxes of neutral gas (helium). However the technique used in this experiment did not detect hydrogen, which is the main component of the interplanetary neutral gas.

Principles of operation of the GAS 2 instrument specially designed for the detection of neutral atoms (especially H) in the solar wind energy range are presented in this paper as well as some results of the calibration of this instrument.

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2 Principles of operation

Detection of neutral hydrogen atoms in the solar wind is complicated by the presence of intense fluxes of Solar photons, the flux of which is by several orders of magnitude higher than that of the solar wind (see, e.g., Bleszynski et al., 1992). In principle fast neutral particles with the energy of about 1 keV can be detected by secondary-electron multipliers. The most convenient ones are channel electron multipliers, such as microchannel plates (MCP). But in the presence of intense light flux, which also generates secondary electrons, these instruments alone cannot directly detect neutral atoms.

In order to overcome this difficulty Gruntman and Leonas (1986) proposed to detect coincidences between photons and particles on one side and secondary electrons emitted from a thin foil by photons and particles on the other side. A diagram of a proper GAS 2 instrument is given in section III of Fig. 1. A solar baffle (1) with permanent magnet (2) is located in front of the main GAS 2 unit for the deflection of charged particles and attenuation of photon flux by a factor of more than 10^7 (Figliewicz et al. 1991; Hlond, 1996). GAS 2 sensor includes a thin ~ 100 Å carbon foil (3) supported by a grid of 5 μm wire with a mesh width of 30 μm), two electrostatic mirrors (4) and three detectors D_{1-3} based on MCP plates. Electrostatic mirrors steer electrons emitted from the foil to detectors D_1 and D_2.

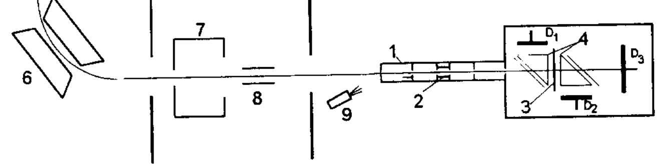

Fig. 1 Scheme of the IPM test facility and GAS 2 instrument.

Fast neutral particles and photons passing across the baffle hit a carbon foil. A photon may emit an electron from the upstream surface of the foil and be detected by D_1, or emit electron from the downstream surface and be detected by D_2, or pass through the foil without emitting an electron and be detected by D_3. The photon due to its small energy ~ 10 eV can cause only one such event.

A fast neutral particle may also emit electron from the upstream or downstream surface of the foil, but, in contrast to a photon, the particle can be simultaneously detected by D_3. Fast particle due to its very large energy ~ 1 keV can cause simultaneously two or even three such events. If the instrument detects coincidences between D_1 and D_3, or D_2 and D_3, or D_1, D_2 and D_3 signals (within a preselected time interval of ~ 500 ns), 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 coincidence only when two photons are consecutively detected within a time interval of ~ 500 ns.

Besides, the GAS 2 can evaluate the energy of heavy particle provided that its mass is known by measuring the time of flight (TOF) over a base distance ~ 6 cm between the thin foil and the detector D_3. The start signal is taken from D_1 or D_2, depending on which side of the foil detected electron is emitted (taking into account the transit time between the foil and detectors D_1 or D_2). The stop signal is generated in D_3 by heavy particles. The time of flight of each particle is digitized and defines a number of the counting channel in the data storage in which the stored number is incremented. Given sufficient detected events, the instrument yields a time-of flight spectrum that can be easily converted to an energy spectrum. Count rates of each detector are also recorded.

In laboratory tests, GAS 2 was driven by ground support equipment based on personal computer with dedicated interface (Hlond, 1991).

3 Calibration facilities and results

The laboratory tests of GAS 2 were carried out in two facilities. First calibration facility, schematics of which is given in sections I, II of Fig. 1, was assembled in Institute for Problems in Mechanics (IPM, Kalinin et al., 1995). It includes an ion source (5), mass separating magnet (6), charge-exchange chamber (7), ion-deflecting plates (8) and UV lamp (9). All vacuum sections I-III are pumped with separate pumps.

The ion beam generated by the ion source is accelerated to the required energy and is deflected by magnet for separation of ions over mass. Then the beam is directed to the charge-exchange chamber where a fraction of ions are neutralized. Ions that are not neutralized are removed from the beam by the deflecting plates. The hydrogen UV lamp acts as a source of photons.

Measurements were performed both with and without baffle. Ion beams could be detected without the baffle. 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 instrument. We have tested the detection of H_2, He, H_2^+ and He^+ beams with energies of 1 to 4 keV.

Fig. 2a shows the energy spectra of hydrogen molecules and helium atoms with energy of 6 keV as measured by GAS 2 instrument No. 001. The spectra are shifted compared to initial particle energy because of the energy loss in the foil. Energy losses in the foil used as well as the energy spreading after the foil are small enough for 6 keV particles. Narrower energy spreading for heavier helium atoms corresponds to theoretical expectations. Similar spectra were recorded with other atoms, molecules and ions.

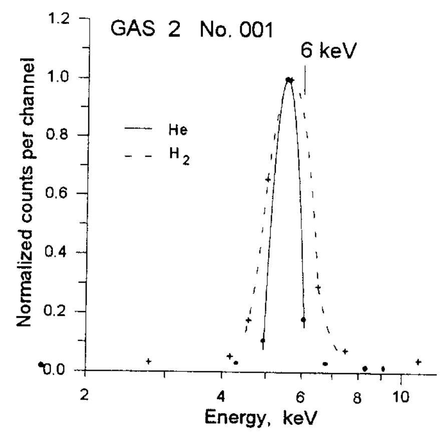

Fig. 2 Energy spectra of originally 6 keV H_2 molecules and He atoms after the foil of No. 001 GAS 2 instrument.

Fig. 3 combines the energy spectra of helium atoms with energy of 3 keV and 6 keV as measured by GAS 2 instruments No. 001 and No. 002. For both instruments relative loss of energy in the foil and energy spread after the foil for 3 keV neutral particles are larger than those for 6 keV particles. Larger losses and spreads for No.002 instrument are connected with thicker foil in this case.

The GAS 2 instruments were 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 (Hsieh et al., 1980). It turned out that the spectrum of atoms is efficiently measured using double coincidences with a ratio of the flux

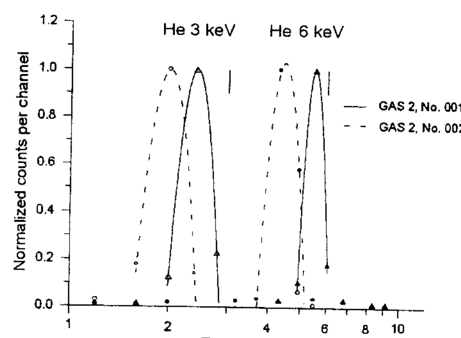

Fig. 3 Energy spectra of originally 3 keV and 6 keV He atoms after the foils of No. 001 and No. 002 GAS 2 instruments.

of photons to that of neutral particles ~ (5 - 7)$\cdot 10^4$. In this case the neutral particle fluxes ranging between 10^2 - 10^4 cm^{-2}c^{-1} can be detected.

The second calibration facility for energetic neutral atom detector was designed in Max-Planck Institute für Aeronomie (MPAE). The goal of this facility was to perform the absolute calibration of the GAS 2 sensor. MPAE facility scheme is presented in Fig. 4. It consists of two main parts: ion source, specially designed charge-exchange chamber with an ion deflector. Energetic ions are neutralized in the process of charge-exchange reaction:

$$A^+_{fast} + B \rightarrow A_{fast} + B^+,$$

where A^+_{fast} is a fast energetic ion, B is a slow atom in charged exchange chamber, A_{fast} is an energetic neutral atom, and B^+ is a slow ion. The pressure is much higher (more than two orders of magnitude) inside than outside charge-exchange chamber. Hence the charge-exchange is well-localized process. In this case the current of slow ions B^+ well represents the total flux of the fast neutral beam. The construction of charge-exchange chamber made it possible to measure current of slow ions. All the walls of charge-exchange chamber are electrically isolated from each other and there is a grid that is charged up to a positive potential. Such potential, on one hand, repels newborn ions from exit wall of charge-exchange chamber.

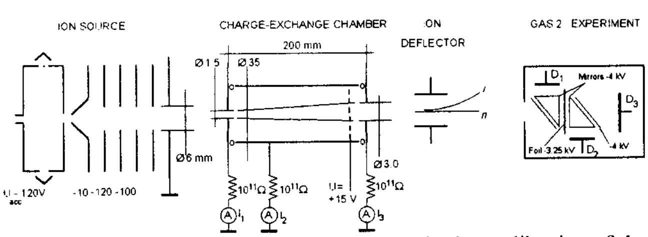

Fig. 4 Scheme of MPAE facility used for the absolute calibration of the GAS 2 instrument.

Assumptions used during calibration:

1) Total flux of fast neutral particles escaping from charge-exchange chamber F_n [s^{-1}] is approximately equal to the current of slow ions I_i/e produced during charge-exchange of fast ions in the chamber:

$$F_n \approx f I_i/e,$$

where f is a fraction of neutrals that passed through the chamber exit hole of 3 mm.

2) I_i current was evaluated by subtraction of currents measured with (I_2') and without (I_2'') neutral gas in the charge-exchange chamber:

$$I_2' \approx I_2'' + I_i.$$

Subtraction of relatively large currents I_2' (e.g., 23 mV/10^{11} ohm) and I_2'' (e.g., 22 mV/10^{11} ohm) leads to relatively large uncertainty of I_i ($\approx$ 1 mV/10^{11} ohm) and F_n evaluations due to instability of current measurements about 0.2 mV/10^{11} ohm.

3) The value of f was determined under assumption that a fraction of passed fast neutrals is equal to a fraction of passed fast ions (additional scattering of fast neutrals during charge-exchange assumed to be negligible). Measurements of I_3 current for usual charge-exchange chamber position and I_3' current in a case when charge-exchange chamber was turned around 1.5 mm entry hole (and all ions collided to the wall of the chamber) provided the following fractions:

$$f \approx (I_3' - I_3)/I_3'.$$

These fractions necessary for the absolute calibration are presented in Table 1 for helium atoms and hydrogen molecules.

Energy, keV	f(He)		$f(H_2)$
	GAS 001	GAS 002	GAS 001
2		0.48	0.34
3	0.52	0.67	
4	0.62	0.75	0.69
5		0.71	
6	0.85	0.86	0.80

Table 1. Fraction of neutrals f passing through the charge-exchange chamber exit hole of MPAE calibration facility.

The pressure of remaining gas near the GAS 2 instrument was about $2\cdot 10^{-6}$ torr without gas supply to the ion source and to the charge-exchange chamber, and about (3-4) 10^{-6} torr with gas supply.

Calibration measurements were realized with switched off ion gauge because slow ions originating from the ionization of the remaining gas by this gauge could be registered by GAS 2 instrument. The absolute efficiencies P of different detectors of the instrument were determined by following relations:

$$P_1 = \frac{N_1}{\tau F_n}, \quad P_2 = \frac{N_2}{\tau F_n}, \quad P_3 = \frac{N_3}{\tau F_n},$$

where N_1, N_2, N_3 are the counts of D_1, D_2, D_3 detectors integrated over time interval τ. Fig. 5 presents the energy dependence of the absolute efficiency of $D_{1,2}$ detectors of the No. 002 GAS 2 instrument. Lower efficiency of the D_2 detector can be explained taking into account that D_2 registers secondary electrons released *after* the neutral particles passed the foil and were partially lost in it.

Comparison of the absolute efficiencies of both No. 001 and No. 002 GAS 2 instruments D_3 detector is presented in Fig. 6. Lower efficiency of No. 002 instrument is connected with the thicker carbon foil in it (see also discussion of the

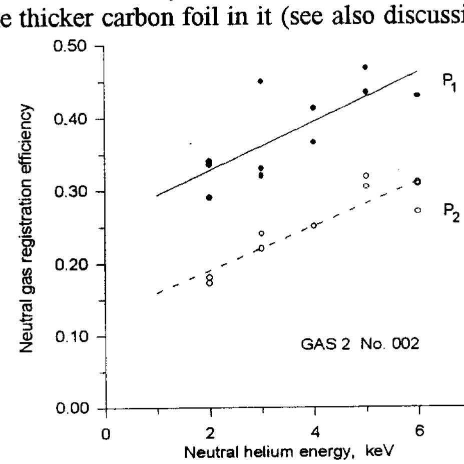

Fig. 5 The energy dependence of the absolute efficiency of $D_{1,2}$ detectors of No. 002 GAS 2 instruments for helium atoms.

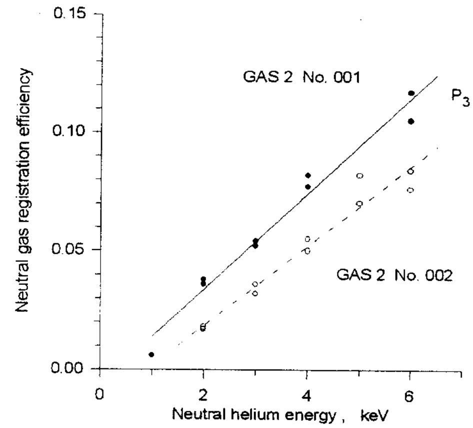

Fig. 6 The energy dependence of the absolute efficiencies of D_3 detectors of No. 001 and No.002 GAS 2 instruments for helium atoms.

data in Fig. 3).

For calculation of the absolute efficiencies for double P_{13}, P_{23} and triple P_{123} coincidence rates the sums of the counts in proper TOF spectra Σ_{13}, Σ_{23}, Σ_{123} were considered:

$$P_{13} = \frac{\Sigma_{13}}{\tau F_n}, \quad P_{23} = \frac{\Sigma_{23}}{\tau F_n}, \quad P_{123} = \frac{\Sigma_{123}}{\tau F_n}.$$

Double coincidence efficiencies for No. 001 GAS 2 instrument are presented in Fig.7. These efficiencies are naturally lower than single detector D_3 efficiency P_3, which is also shown in the figure. On the other hand it is double and triple coincidence rates that are expected to be especially useful during measurements of the neutral particles coming from the solar direction. It is connected with mentioned above ~ 10^5 suppression factor of the parasitic photon registration by the coincidence techniques.

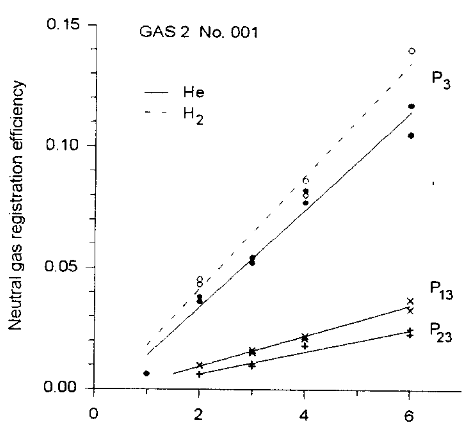

Fig. 7 The energy dependence of the P_3, P_{13}, P_{23} absolute efficiencies of No. 001 GAS 2 instruments for helium atoms and hydrogen molecules.

Greater P_3 efficiency of the H_2 molecules registration compared to that of He atoms is, possibly, connected with the dissociation of the H_2 molecules while passing the carbon foil. Two resultant fast H atoms will be registered with greater efficiency by D_3 detector than one He atom.

4 Conclusions

The laboratory tests of the GAS 2 instrument designed for the detection of neutral atoms from solar direction demonstrated its reasonable performance and confirmed its ability of effective suppression of parasitic UV radiation.

The principles of operation of the facility for the absolute calibration of instruments for neutral particle measurements are described.

Results of the GAS 2 calibrations can be used for the absolute measurements of the neutral component of the solar wind.

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