Sampling of biological particles using high-frequency electric and magnetic fields

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Specific polarizability of bioparticles is, as a rule, much higher than that of inorganic particles. This difference makes up the basis for separating of different particles in the process of their sampling in the upper atmosphere and in space. The possibility of spatially separating particles further (after retarding) by making use of the difference in polarization is discussed. A device that is similar to the known mass spectrometer is proposed, but it operates with neutral particles instead of charged ones and a superposition of alternating electric and magnetic fields is used as a deflecting field. Under the exposure to an alternating electric field, the polarization current is induced, which interacts with the orthogonal phased-in magnetic field, and a particle occurs under the effect of a deflecting force proportional to the particle polarizability.

Sampling and analysis of biogenic particles in the upper atmosphere and in space are interesting in connection with several practical tasks. One of them is quantitative probability estimation that life on Earth has been brought from space. Another problem is associated with the space missions and appearance of space debris.

We have developed a sampler of biogenic particles to be used in space and in the upper atmosphere.

Space debris resulting from explosion of space objects may contain biogenic particles as well. The number of such particles of micron and smaller size is estimated to be 10^{13}–10^{14} (Refs. 1 and 2).

Sampling of biogenic particles is needed to study transformation of large molecules of biological origin (proteins, nuclein acids, including fragments of virus DNA) as a result of long exposure to outer space factors.

The specific polarizability of biogenic particles is usually far higher than that of inorganic particles. This difference can be used as a basis for separation of particles in the process of their sampling from the upper atmosphere and from space. A device for particle retarding from the speed of 7–10 km/s to several meters per second in order to provide for sparing sampling of biogenic particles was described in Refs. 2 and 3. In this paper we consider the possibility of their further (after retarding) separation according to the degree of polarizability.

The device layout is shown in Fig. 1. This sampler can be installed onboard the International Space Station. It has a resonator for particle retarding described in Refs. 3 and 4. The entrance window of the sampler is oriented so that the excess residual gas pressure caused by the velocity head is produced in the resonator cavity. The velocity head $P = \rho v^2/2 \approx 10^{-1}$ Pa is formed due to sampler movement at a speed $v \approx 7 \cdot 10^3$ m/s in the static medium with the residual gas density $\rho \approx 10^{-8}$ kg/m^3.

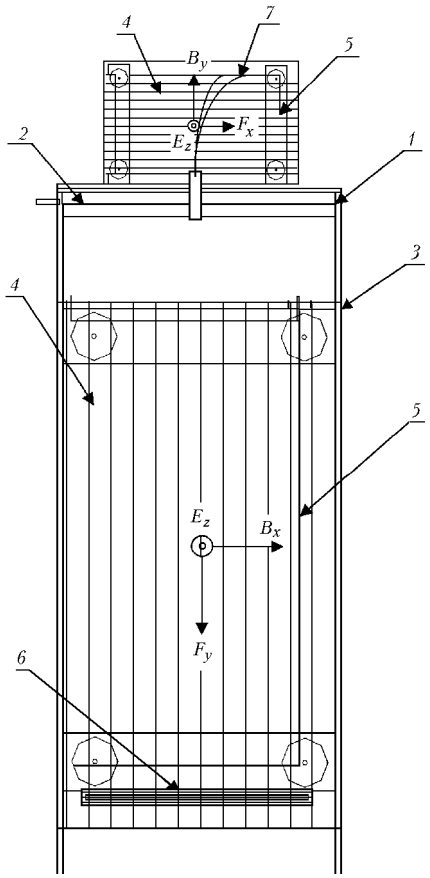

Fig. 1. Device for retarding and spatial separation of biogenic particles by high-frequency electric and magnetic fields: detachable sampling collector *1*, precipitator electrodes *2*, resonator housing *3*, solenoid *4*, capacitor plates *5*, electron gun *6*, trajectories of particles to be separated *7*.

The presence of the residual gas in the resonator cavity allows particles of the size $R = 10^{-8}$ m to be retarded. Then they are let out along with the gas flow

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through a small hole at a low rate into the space behind the sampler. In this space the low residual gas pressure $P \approx 10^{-10}$ Pa is established.

The available theoretical and experimental data show that under the orbit conditions a zone of superhigh vacuum is formed in the aerodynamic trail behind a flat bottom of short-extension bodies oriented normally to the velocity vector.[5]

The deflector is located behind the sampler in the aerodynamic trail and consists, as the main sampler, of a resonator, in which the electric field strength component E_x directed normally to the direction of resonator motion is formed along with the magnetic component B_y. Time dependence of the amplitudes of these fields can be expressed as follows:

$$E_x = E_0 \sin \omega t, \; B_y = B_0 \cos \omega t. \qquad (1)$$

A particle in the resonator is polarized under the effect of high-frequency electric field. Due to interaction with the electric component E_x, the particle acquires the dipole moment

$$d_x = \alpha\varepsilon_0 E_x = \alpha\varepsilon_0 E_0 \sin \omega t, \qquad (2)$$

where α is the particle polarizability, and ε_0 is the dielectric constant of vacuum.

The change in the electric field strength induces the polarization current in the particle:

$$j_x = \frac{1}{l}\frac{\mathrm{d}d_x}{\mathrm{d}t} = \frac{1}{l}\alpha\varepsilon_0\omega E_0 \cos \omega t. \qquad (3)$$

The polarization current interacts with the magnetic field of the resonator, and this manifests itself in the deflecting force F_z acting on the particle from the part of the magnetic field:

$$F_z = j_x B_y l = \alpha\varepsilon_0\omega E_0 B_0 \cos^2 \omega t, \qquad (4)$$

where l is the particle length.

The mean deflecting acceleration is

$$a_z = \frac{F_z}{m} = \frac{\alpha\varepsilon_0\omega E_0 B_0}{2m}. \qquad (5)$$

Under conditions of space vacuum at high strength of the high-frequency electric field, the particle acceleration a in the deflector is 10 m/s^2. At such acceleration, particles with the size $R \approx 10^{-8}$ m, which is hypothetically characteristic of space biogenic particles, for example, proteins or fragments of DNA molecules, are deflected.

Assume $\alpha = 10^{-22}$ m^3, $E_0 = 10^6$ V/m, $B_0 = 10^{-2}$ T, $m = 10^{-21}$ kg, $\omega = 10^9$.

Having substituted these values into Eq. (5), we obtain $a_z = 5$ m/s^2.

At such acceleration, a particle moving at a speed of 1 m/s is deflected by 30° at the distance of 0.1 m. Particles having different polarizability are deflected by different angles and thus they are spatially separated depending on their polarizability.

Thus, the device for sampling biological particles based on particle separation according to their degree of polarizability can be applied to determine the amount of particles with different polarizability under space flight conditions, as well as it can be used in laboratory practice in various configurations.[6–9]

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