NEW METHOD OF MEASUREMENT OF HYDROGEN ISOTOPES IN SURFACE LAYER OF PLANETARY SOILS BY SPECTROSCOPY OF RECOIL PROTONS FROM ELASTIC SCATTERING OF ALPHA-PARTICLES

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Introduction. Results of the studies of lunar soil composition by Alpha-Proton Spectrometers on the "Surveyor" spacecrafts [1] and "Mars Pathfinder" [2] have demonstrated the usefulness of *in-situ* measuring instruments employing radioactive sources of alpha-particles and modern semiconductor detectors.

Nevertheless, the methods of alpha-particle backscattering and alpha-particle induced X-ray emission, used in the above mentioned instruments, do not allow determining hydrogen, which may be present in soils as crystal hydrates or in some other form.

One method used in laboratories for the determination of hydrogen in surface layers of samples [3] consist in the measurement of protons scattered in the forward direction in the process of elastic scattering of alpha-particles from accelerators on hydrogen nuclei. The authors are, however, not aware of an application of this method using alpha-particles from radioactive sources. As shown below, such a method appears feasible for the determination of hydrogen in surface layers of solar system bodies (planets, their satellites, asteroids and comets) by means of in-situ measuring instruments.

Method. The physical process underlying the proposed method is the elastic scattering of alpha particles on hydrogen isotope's nuclei. The energy of the recoil particle E in the coordinate system, where the energy of the alpha particle is equal to E_0 and target nuclei (hydrogen isotopes) are at rest is described by the following equation:

$$E = E_0 \frac{4 m_0 m}{(m_0 + m)^2} \cos^2(\theta) \qquad (1)$$

where m_0 and m are the masses of alpha-particles and hydrogen nuclei correspondingly, and θ is the angle between the velocity vectors of the alpha-particles and the recoil particles. For alpha-particles with 5.8 MeV energy and a mean scattering angle θ about 7° the maximum energy is 3.7 MeV for recoiling protons and 5.1 MeV for recoiling deuterons. Dependence max energy protons and deuterons from scattering angle θ showed Fig.1.

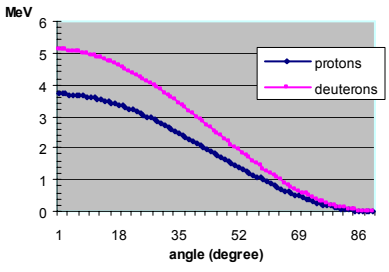

Fig.1. Dependence max energy protons and deuterons from scattering angle.

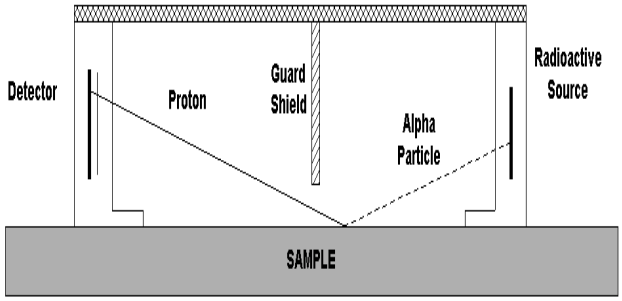

Fig.2 A Scheme of the instrumental setup for the spectroscopy of recoil hydrogen atoms scattered in forward direction.

The experimental model of a hydrogen spectrometer used in this work consisted of a block of detectors of an Alpha-Proton-X-ray-Spectrometer designed for "Mars-96" (similar to the instrument used on "Mars-Pathfinder"), three 244Cm sources with a total activity ca. 12 mCi, and the associated electronics. Sources and detectors were arranged in geometry as shown in Fig.2. Effective depth of sample from hydrogen measured is ~5÷20 μm depending on the atomic weight of the sample, density of it and angle θ.

Experimental results. With the help of this experimental setup proton spectra of samples with different hydrogen content were recorded and counting rates of forward scattered protons determined

(Figs. 3 & 4). In all calculations of hydrogen concentration $KHCO_3$ powder, having 1 wt.% of hydrogen, was used as a standard. Sufficient measurement durations assured data with good statistical accuracies (σ~1 % in most cases). For defenses from electromagnetic noise spectra are discriminate on level energy 1.5 MeV.

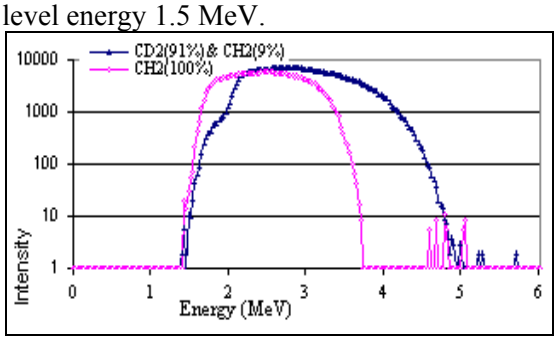

Fig. 3. Spectra of protons and deuterons scattered in the forward direction for H- and D-polyethylene.

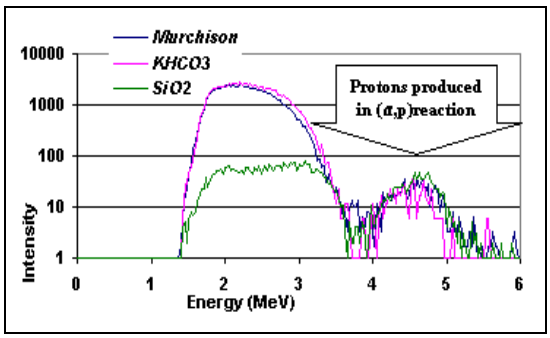

Fig. 4. Spectra of protons scattered in the forward direction from a carbonatious meteorite and two standard samples.

The spectra in Fig.3 show that the maximum energies of recoil protons and deuterons are in the good agreement with theoretical calculations and the separation of the maximum energies of 1.16 MeV even permit to measure the ratio of hydrogen to deuterium for a wide range of concentrations.

The shapes of proton spectra of some samples, shown on Fig.4, demonstrate the independence of the spectral distribution of protons from the elemental composition of the sample. Their intensity is deter-mined only by the content of hydrogen (Murchison - 1 wt.%, $KHCO_3$ - 1 wt.%, SiO_2 < 0.036 wt.%). As to the contribution of protons from (α, p) - reactions, their intensity does not exceed 0.1% of the total intensity in the energy range of interest.

Conclusions. For the Martian soil about 1% by weight H_2O have been estimated [4,5], included measuring gas chromatographs and mass spectrometers on Viking 1,2 and last data from instrument HEND of mission Mars-Odyssey. The proposed method would allow the measurement of such concentrations by means of a very compact device with tens of times smaller mass than with gas chromatographs and mass spectrometers. And we have new type of an instrument for an *in-situ* measurement of hydrogen in surface layer of solid materials. The installation of this device on small rovers should allow the performance of such measurements on different soil samples with characteristic size of several centimeters. This method will result in the development of a combined with the abilities of the APX instrument the developed method will allow to measure the full range of chemical elements from hydrogen to the heavier ones within one portable instrument, which is very important in planetary research. Together with small mass and power consumption the outstanding advantage of the method is that it also allows measuring deuterium to hydrogen ratio (with limited concentration higher then 0.01 wt.%).

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