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CONSIDERATIONS ON THE PLANNED USE OF A SCIENTIFIC BALANCE ON MARS
Part I. Gravimetric sorption experiment

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Future European and American Missions to Mars will be focussed on the search for life, and of water, as a precondition for the existence of complex organisms. Besides the polar ice caps of carbon dioxide and water, in the upper few meters of the Martian surface, water and ice bound to the soil surface, is expected. Therefore we propose to investigate the storing capability of Martian soil in situ. This planned quite new type of investigation makes use for the first time of a balance at a celestial body outside Earth.

Keywords: *adsorption, gravimetry, Mars, surface, water*

Water on Mars

Future European and American Missions to Mars will be focussed on the search for life, and of water, as a precondition for the existence of complex organisms [1]. On Mars there is, at present, no liquid bulk water. Data on geological structure leads to the assumption that 3.8 billion years ago rivers and oceans existed on Mars. Today the thin atmosphere provides no obstacle to the solar wind consisting mainly of electrons and α-particles (helium cores). Those particles penetrate down to 270 km above the surface and displace atmospheric molecules. Thus Mars loses water continuously.

The poles of Mars are covered with ice and solid carbon dioxide (Fig. 1). The surface temperature at mid and low latitudes on Mars varies diurnally and seasonally between about 140 and 300 K, whilst the temperature at depths of a few decimetres and deeper has a practically constant value of about 220 K (Fig. 2). Over geological time scales, only physisorbed and chemisorbed water is expected to be present in the soil material in depths deeper than about 0.1 m [2–4]. Measurements of the water content of the upper Martian surface by remote observation of neutron scattering results have indicated that water content of between about 2–16% by mass is characteristic for the upper few meters of the Martian surface at mid and low latitudes [5] (Fig. 3). The Martian atmosphere consists mainly of carbon dioxide with small proportions of nitrogen, ar-

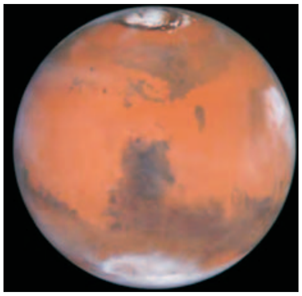

Fig. 1 Mars

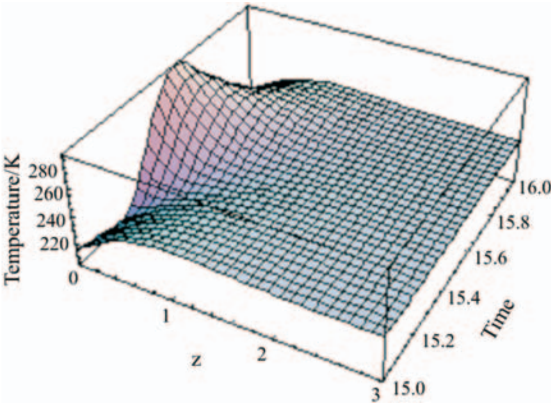

Fig. 2 Diurnal behaviour and depth dependence of the Martian surface and subsurface temperature field. The depth *z* is given in units of the diurnal penetration depth *LT*=1.52 cm, and the time is that of the 20th rotation, when a stable solution is reached. Albedo *A*=0.3, thermal inertia *I*=64 W $s^{1/2}$ m^{-2} K^{-1}

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Table 1 Main atmospheric components by volume and their properties [3, 7], measured at the Viking landing sites, relative to a total pressure of 750 Pa according to Wilson [2]

Species	Abundance volume parts	Melting point/K	Boiling point at 1 bar/K	Molecular mass	Liquid density/g cm^{-3}	Number of molecules/ (monolayer m^2)$^{-1}$
CO_2	0.9532	216.6	194.7	44.01	1.101^{195}	$5.34\cdot10^{18}$
			at 5.2 bar sublimation			
N_2	0.027	63.3	77.4	28.01	$0.8081^{77.4}$	$8.10\cdot10^{18}$
Ar	0.016	83.96	87.5	39.948	1.40^{236}	$8.54\cdot10^{18}$
O_2	0.0013	54.76	90.2	31.9988	1.149^{90}	$8.71\cdot10^{18}$
CO	0.0007	74.16	81.7	28.01	0.793	$8.07\cdot10^{18}$
H_2O	0.0003 ~0.00016*	273.16	373.16	18.01534	0.9168^{273}	$5.27\cdot10^{18}$

*Annual global average of water is ~10 g m^{-3}.

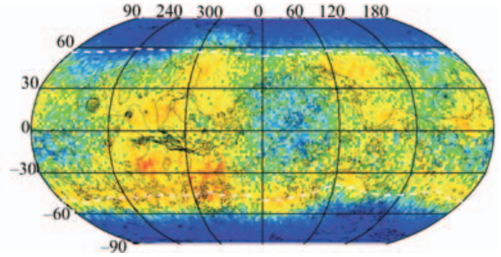

Fig. 3 Map of epithermal neutrons emission from frost-free surface of Mars from HEND/Odyssey. Blue pixels represent region with high content of water in 1–2 m

Fig. 4 Morning fog on Mars

gon, oxygen, and a few other gases (Table 1) at an average total surface pressure of about 600 Pa (depending on altitude) [2–6]. Water vapour is identified in the atmosphere with a partial pressure at the surface of about 0.1 Pa. This can locally reach saturation during cool nights and morning hours. The upper millimetre of the Martian surface interacts with atmospheric water vapour by condensation processes, adsorption and freezing. Morning fog and frost are the observable consequences of these interactions (Fig. 4).

The water/soil interface

Down to temperatures of about 33 K, some few physisorbed layers at solid surfaces, including that of the ice surface, are movable quasi-liquids [8, 9]. In contrast to the conditions in ice the hydrate bindings of molecules in vicinal layers are incompletely saturated and try to reconstruct a more stable configuration [10–13]. Though movable, these water layers are bound to the surface and their removal requires energy, and of course, when removed we get ice. The terrestrial analogue is 'unfrozen water' in permafrost, which is shown to remain free liquid water down to temperatures of –40°C and less.

Movability of water molecules is a prerequisite for chemical reactions including such reactions, which are important for life. It has been shown experimentally that the above mentioned amount of adsorbed water is, in Mars-analogue soils, able to trigger chemical reactions [4, 6]. If life still exists on Mars, this should be in the form of micro-organisms and should be found most probably at the solid/ice interface.

It is to be expected that water in contact with soil is not pure but contains salt ions. In the ice/salt water interface strong concentration gradients are present which can be used energetically [14]. Thereby the binding forces of adsorbed water may be overcome and this water could be made usable for living species. Such processes occur at roots and in cell walls.

It is currently one of the great current challenges in Martian research to obtain a better knowledge of the geometric microstructure of the soil and of the reactions occurring there.

Proposal for a gravimetric experiment

In the present paper we report on the preparation of gravimetric sorption measurements for the first time and in situ with the aim of obtaining the surface properties of Martian soil with regard to water storage. The most important parameters are the specific surface area, the pore size distribution and the storage capacity for water.

With regard to the conditions on Mars a gravimetric sorption experiment with soil/atmosphere turns out to be very simple. Besides a balance to measure the adsorbed quantity of gas, temperature and pressure sensors are required. Both types of sensors are included in the standard equipment of the payload. Requirements with regard to resolution, sensitivity and specified measuring range of the balance and the other sensors are modest. The balance should be loaded sequentially with soil samples. During the diurnal temperature cycle of about 100 K, variations of the adsorbed mass should be measured as a function of time. The adsorbed amount depends on size and structure of the sample surface, temperature and atmospheric partial pressure. From the experimental curves specific surface area and pore size distribution can be calculated.

In terrestrial laboratories such plots must be measured in advance using the expected conditions on Mars and a set of data and equations must be developed for their evaluation.

Assessment of the effect

The values in Table 1 show that only carbon dioxide and water are condensable in the temperature range between 150 and 290 K and may be adsorbed in noticeable amounts. Above 0°C in particular, water will be adsorbed. Since fog and clouds near the surface were observed saturation conditions may occur. Under such conditions, about eight layers of water molecules may be adsorbed at the surface of soil material and in addition pores may be filled [2]. With lower temperatures carbon dioxide is also adsorbed increasingly and will sublime at its freezing temperature.

The determination of the specific surface area is based on the measurement of the mass of one complete monolayer adsorbed at the surface of soil material [15, 16]. Thus, the measuring range of the planned instrument should cover the mass range of at least one layer of H_2O or CO_2, respectively. The monolayer capacity m_m amounts to

$$m_\mathrm{m} = \frac{N_\mathrm{m} M A_\mathrm{s}}{N_\mathrm{A}} \qquad (1)$$

where M stands for the molecular mass, N_m the number of molecules per monolayer, N_A Avogadro's constant=$6.022\cdot10^{23}$ mol^{-1} and A_s the specific surface area of the sample. This results in a monolayer mass of 158 μg m^{-2} for water, and 385 μg m^{-2} for carbon dioxide. The mean specific surface area A_s of Martian soil is estimated to be 17 m^2 g^{-1}. So we may expect mass variations of several milligrammes by adsorption at a 1 g sample. This corresponds to a required relative sensitivity of 10^{-3} for the balance. The determination of the pore size distribution is based on the measurement of the complete isobar, and the mass of several layers must be measured. To allow a resolution of the fine structure of the isobar the relative sensitivity of the balance should be better than 10^{-3}.

Conclusions

We propose a gravimetric experiment on Mars to determine the geometric surface structure of the soil. The results should give a basis for the quantitative calculation of chemical and physical processes occurring in the soil, in particular with water. The quite new type of planned investigation makes use of a balance at a celestial body outside Earth for the first time.

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