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PLANNING OF GRAVIMETRIC INVESTIGATIONS ON MARS

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Abstract

We propose to install a balance at the surface of Mars. In this paper we present a survey on tasks which could be accomplished by means of a balance. The determination of the specific surface area and porosity of Martian soil and other sorption experiments are discussed. Criteria for the choice of a suitable balance type are given.

Keywords: balance, gravimetry, Mars, specific surface area, water adsorption

Introduction

The European ExoMars Rover Mission, which is prepared by ESA for a launch in 2009, is devoted to the search for life or traces of it, and of water, as a precondition for the existence highly complex organisms. The surface temperature at mid and low latitudes on Mars varies diurnally and seasonally between about 140 and 300 K; while the temperature at depths of a few decimeters and deeper is of a practically constant value of about 220 K. The Martian atmosphere consists mainly of carbon dioxide with small proportions of nitrogen, argon, oxygen, and a few other gases at an average total surface pressure of about 600 Pa (depending on altitude) [1–4]. Under such conditions, water can in the upper meters of the Martian surface exist permanently, i.e. over geological time scales, as sorbed water only. Ice sublimes faster than adsorbed water evaporates by several orders of magnitude. Therefore, ice is expected to exist in the Martian mid and low latitudinal upper surface only temporarily. Physisorbed and chemisorbed water is therefore expected to be present in the soil material in depths between about 0.1 m down to about (1–2) m [1, 4–5]. Here it has to be noted that adsorbed water has liquid-like properties in the sense of a two-dimensional liquid. The terrestrial analogue is the ‘unfrozen water’ in permafrost, which is shown to remain liquid-like down to temperatures of –40°C and less. This presence of liquid-like adsorption water in the upper Martian soil may have remarkable consequences in terms of triggering chemical processes. Measurements of the water con-

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tent of the upper Martian surface by remote observation of neutron scattering results have indicated that a water content of between about 2–16% by mass is characteristic for the upper meters of the Martian surface at mid and low latitudes [3].

Furthermore, water vapour is identified in the atmosphere with a partial water vapour pressure at the surface of about 0.1 Pa. This can locally reach saturation during cool nights and morning hours. The upper millimeter of the Martian surface interacts with this water vapour by condensation processes, adsorption and freezing. Morning fog and frost are the observable consequences of this interaction. It is one of the great current challenges in Mars research to measure the following for the first time and in situ:

- the water content and its variation at the Martian surface
- the sorption properties of the soil
- specific surface and porosity of the soil
- sorption capacity and swelling ability
- atmospheric humidity and pressure.

In this paper we report on the preparation of gravimetric sorption measurements with the aim of obtaining the above mentioned surface properties of Martian soil with regard to water storage.

Tasks for a balance on Mars

The most widely used complex measuring instrument in science is still the balance. Therefore, it seems to be reasonable to install a balance also on Mars. Gravimetric investigations on Mars, however, are restricted because only automatic and remote controlled measurements can be made. Useful tasks there could comprise the determination or investigation of:

- local gravitational field
- specific surface area and porosity (pore volume and pore size distribution) of soil
- sorption properties of soil and sorption processes with atmospheric components
- chemical variations (e.g. decomposition) of soil components
- atmospheric humidity and pressure
- density of soil material by buoyancy.

Sorption experiments

The present proposal concerns the investigation of the geometric surface structure of Martian soil and of sorption processes. For that purpose the mass of a soil sample should be recorded as a function of time. Because at Mars the temperature in the day/night circle varies by about 100 K, atmospheric components will be adsorbed during night and desorbed during day. The corresponding equatorial extreme temperatures are for northern spring equinox of 180 K in the morning and of 280 K in the early afternoon. The adsorbed amount depends on size and structure of the sample surface, temperature and atmospheric partial pressure. Therefore, the internal structure of the sample under consideration must remain unchanged during the experiment. From those mass variations the adsorption and desorption kinetics is obtained; this gives some information on the solid material, e.g. microporosity and swelling ability. From equilibrium values of the adsorbed mass at different temperatures sorption isobars can be determined. From these, the specific surface area, the specific pore volume and the pore size distribution can be derived, and the sorption capacity for water can be assessed. To evaluate those composite isobars it seems necessary to measure in advance the isobars of each single component and to compare results with composite isobars on reference materials.

Carbon dioxide and water are the only gases which are condensable as a solid or liquid, respectively, and may be adsorbed in noticeable amounts at Martian conditions. In particular water will be adsorbed above 273 K. Since clouds were observed near the surface, saturation conditions may occur occasionally. Then, up to about eight layers of water may be adsorbed at the surface of soil material, and in addition pores may be filled [6, 7]. With decreasing temperatures also, carbon dioxide is adsorbed increasingly.

The determination of the specific surface area is based on the measurement of the mass of a complete monolayer adsorbed at the surface [6, 7]. The monolayer capacity m_m amounts to

$$m_\mathrm{m} = \frac{N_\mathrm{m} M A_\mathrm{s}}{N_\mathrm{A}} \tag{1}$$

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.

For water, the monolayer mass is 158 μg m^{-2}, for carbon dioxide 385 μg m^{-2}. The mean specific surface area of Martian soil is estimated to be $A_\mathrm{s}\approx17$ m^2 g^{-1} [1]. So we may expect mass variations by adsorption of several mg for a 1 g sample. Thus a balance is required which has a relative sensitivity of at least 10^{-3}.

Instrumentation

An apparatus required for such an investigation consists basically of a recording balance with sample changer. PLUTO on board the Mars Express Lander Beagle 2 is an example of an appropriate sample acquisition and delivery system. The apparatus must be protected against contamination by dust and against heat radiation. For a gravity balance a resilient support is needed. In order to restrict size and mass of the apparatus, a microbalance should be considered with a maximum load of 1 g or below and a measuring range of micro- or milligrams. In this case, samples must consist of particulate soil material as it is given with the Martian regolith. Otherwise, means for preparation and/or size reduction of soil material could be required. In addition, recording temperature and pressure gauges are needed and an air analyser is desirable as part of the complete equipment of the scientific payload. All these instruments must be chosen with regard to the conditions on Mars (corrosive atmosphere, diurnal and seasonal temperature and pressure variations, solar and cosmic radiation and lower gravitational field).

Two types of balances come into question: gravitational balances and impulse balances [8, 9]. There are two sub-types of balances which make use of the gravitational field: spring balances and lever balances. As the mean surface gravity on Mars is 3.74 m s^{-2}, which is less than that on Earth by a factor of 0.38, gravitational balances are less sensitive by that factor.

Spring balances are very simple in design: The extension of a helical spring can be measured by means of an optoelectronic sensor. Its measuring range depends on the design of the spring and can be chosen freely. The relative sensitivity is about 10^{-4}. Changes of the mechanical properties of the spring due to temperature variations have to be compensated finally by the corresponding calibration information. The relatively simple design is an argument in favour of an application for in situ experiments on Mars.

A variety of electromagnetic beam (lever) balances is offered commercially for thermogravimetric or sorptometric apparatus [9]. The beam deflection of such instruments is observed either optoelectronically or electromagnetically and compensated electromagnetically. The compensation consumes some electrical energy. Permanent magnets and electromagnets should be shielded to avoid their influence on other instruments. The relative sensitivity is up to $\sim 10^{-7}$, because mass variations are measured in comparison with a countermass in the gravitational field. This relatively high sensitivity is an argument in favour of this measuring principle. Equal armed balances allow comparison measurement with reference samples.

Because impulse type balances are independent of the gravitational field they can be used as airborne instruments and in space. There exist three sub-types of oscillating systems: crystal balances, band or string and tapered element balances.

Two crystal type balances are used: quartz crystal microbalances (QCM) [10, 11] or $GaPO_4$ crystal sensors [12]. Oscillations are electrically induced and variations of the load are measured by observing the shift in frequency. Quartz crystal balances have already been used in space as contamination sensors. Because of operation by high-frequency vibrations, the sample must be connected firmly to the sensor surface. Therefore such instruments are used exclusively for recording of dust or droplets or as layer thickness monitors in evaporation and sputtering apparatus. In view of the necessary preparations and of the necessary structural conservation of the sample, applications of impulse type balances to in situ experiments on Mars seem to be difficult.

The sensor element of a tapered element balance (TEOM) is a thin-walled metal tube, fixed on a base plate and tapered to the free end, which is excited by oscillations by means of an alternating electric field. Frequency shifts are observed optoelectronically. TEOM's are used as dust and contamination sensors and also as airborne instruments.

In oscillating band or string balances, the element is excited mechanically or acoustically and the vibrations measured by means of optoelectronics or mechanically or acoustically. Because the frequencies applied are much lower than those with other oscillating systems, the connection of sample to sensor is of minor importance. Oscillating band balances are used as dust sensors e.g. in mines. String systems are applied in belt weigher's. Furthermore tuning-fork elements are applied in analytical balances. Unfortunately, all these oscillating balances will have difficulties in preserving the internal structure of loosely bonded samples such as Martian regolith.

Conclusions

With regard to

- its high relative sensitivity and versatility
- its non-destructive sample treatment in view of oscillations

we suggest the use of an equal-armed electromagnetic beam balance [13] for water related in situ measurements at the Martian surface. With regard to its simplicity, a spring balance should be considered alternatively. Advantageously a spring balance does not require a magnet.

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