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Celestial Bodies

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5.1 Introduction

The previous paragraphs have described several parameters that play a role in space. In this paragraph, we focus on conditions occurring on planetary surfaces that are reproducible in a laboratory setting, which include some of the parameters described earlier. Most simulation facilities are designed to reproduce atmospheric pressure and composition, ultraviolet (UV) radiation, and surface temperature. Table 5.1 gives an overview of the surface conditions on several terrestrial bodies, as well as the Moon and Titan. So far, there are no simulation facilities known that focus on other solar system bodies.

The majority of the simulation facilities focuses on a range of planetary surface conditions either for scientific studies or for instrument testing, and examples of these are described below. Some also focus on more specific scenarios, including wind tunnels that are described below as well.

5.2 General Planetary Simulation Facilities

5.2.1 The Centre for Astrobiology Research (CAB), Madrid, Spain

CAB houses a versatile environmental simulation chamber capable of reproducing atmospheric compositions and surface temperatures for most planetary objects. This 50 $\times$ 40 cm chamber was specifically developed to subject samples to in situ irradiation. The internal pressure can be varied between 5 and 5 $\times$ 10^{-9} mbar. The required atmospheric composition is regulated using a residual gas analyzer with ppm precision. Temperatures can be set from 4 K to 325 K UV radiation is provided by a combination of a deuterium

Table 5.1 Selected surface and atmospheric parameters of selected solar system bodies (adapted from [1])

Solar System Body	Mercury	Venus	Earth
Mass (10^{24} kg)	0.33	4.87	5.97
Radius (km)	2,439.7	6,051.8	6,378.14
Density (g cm^{-3})	5.43	5.24	5.52
Surface gravity (m s^{-2})	3.70	8.87	9.80
Temperature (K)	100–700	737	184–330
Escape velocity (km s^{-1})	4.25	10.36	11.18
Length of day (h)	4,222.6	2,802.0	24.0
Atmospheric pressure (mbar)	10^{-11}	95.6×10^3	1,000
Atmospheric composition	42 % O (molecular)	96.5 % CO_2	78.08 % N_2
	29 % Na	3.5 % N_2	20.95 % O_2
	22 % H	0.015 % SO_2	0.93 % Ar
	6 % He	0.007 % Ar	0.036 % CO_2
	Traces Na, K, Ca, Mg	0.002 % H_2O (vapor)	$\sim$1 % H_2O (vapor)
	Mars	Moon	Titan
Mass (10^{24} kg)	0.64	0.07	0.13
Radius (km)	3,396.2	1,738.1	2,575.5
Density (g cm^{-3})	3.93	3.35	1.88
Surface gravity (m s^{-2})	3.71	1.62	1.35
Temperature (K)	130–308	100–390	93.7
Escape velocity (km s^{-1})	5.03	2.38	2.65
Length of day (h)	24.7	708.7	382.7
Atmospheric pressure (mbar)	10	10^{-9}(day)–10^{-12}(night)	1,467
Atmospheric composition	95.32 % CO_2	Ar	82–99 % N_2
	2.7 % N_2	H	1–6 % CH_4
	1.6 % Ar	Na	Traces of
	0.13 % O_2	H	Ar, H_2,
	0.08 % CO	K	C_2H_2, C_2H_4,
	0.03 % H_2O (vapor)		C_2H_6, C_3H_4,
			C_3H_8, C_4H_2,
			HCN, HC_3N,
			C_6H_6, C_2H_2

lamp and a noble gas discharge lamp. The chamber has *in situ* analytical capabilities in the form of UV spectroscopy and infrared spectroscopy (IR). This chamber is especially suitable for following the chemical changes induced in a particular sample by irradiation in a controlled environment. Therefore, it can be used in different disciplines such as planetary geology, astrobiology, environmental chemistry, and materials science as well as for instrumentation testing [2].

5.2.2 Deutsches Zentrum fur Luft-und Raumfahrt (DLR), Berlin, Germany

There are two planetary simulation chambers in the Planetary Emissivity Laboratory at DLR. One is a vacuum chamber (approximately 40 × 30 × 30 cm) and simulates conditions on Venus and Mercury. Samples can reach 773 K and beyond, while keeping the rest of the chamber relatively cold [3]. The second chamber is a Mars simulation facility (MSF). The MSF laboratory consists of a cold chamber with a cooled volume of 80 × 60 × 50 cm. The effective operational experimental chamber, which is cooled within the cold chamber, is a cylinder with inner diameters of 20.1 × 32.4 cm. This chamber operates at 6 mbar CO_2 pressure at 198 K [4].

5.2.3 The Open University, Milton Keynes, UK

This Mars simulation facility consists of a large chamber (90 × 180 cm), providing pressure and temperature conditions representative of the surface conditions on Mars. This chamber is configured with the capability to incorporate large-scale regolith experiments not usually possible within standard vacuum systems. Another chamber is a small Mars chamber (70 × 100 cm) providing a simulated Martian environment with a solar illumination facility designed for instrument qualification and astrobiology experiments. The facility is also configured to permit automated variation of the environment, such as thermal diurnal cycling [5].

5.2.4 Mars Environmental Simulation Chamber (MESCH), Aarhus University, Denmark

MESCH (Figure 5.1) is a dynamic simulation facility, providing low temperature (down to 133 K), low atmospheric pressure (5–10 mbar), and a gas composition like that of Mars during long-term experiments. The main chamber is cylindrical cryogenic environmental chamber, with a double wall providing a cooling mantle through which liquid N_2 can be circulated. The chamber is equipped with an atmospheric gas analyzer and a xenon/mercury discharge source for UV generation. Exchange of samples without changing

Figure 5.1 The Mars environmental simulation chamber. *Image credit* Mars Simulation Laboratory, Aarhus University.

the chamber environment is possible through a load lock system consisting of a small pressure-exchange chamber that can be evacuated. Within the MESCH, up to 10 steel sample tubes can be placed in a carousel that is controlled by an external motor to allow any desired position. A wide variety of experiments is possible through computer logging of environmental data, such as temperature, pressure, and UV exposure time, and automated feedback mechanisms [6].

5.2.5 The Planetary Analogues Laboratory for Light, Atmosphere and Surface Simulations (PALLAS), Utrecht University, The Netherlands

PALLAS (Figure 5.2) is designed to study organic processes in a planetary surface environment, simulating ultraviolet radiation, surface temperature, humidity, and atmospheric composition. PALLAS is a $50 \times 50 \times 50$ cm stainless steel vacuum chamber equipped with a differentially pumped sampling volume for real-time atmospheric measurements, the atmospheric sample chamber (ASC). The ASC is equipped with a turbo pump attached to a diaphragm pump, a mass spectrometer, and a pressure gauge. A xenon arc discharge lamp provides the desired solar spectrum and irradiates the samples through a UV-transparent fused-silica window. An airtight tube is mounted between the lamp housing and the fused-silica window and can be filled with N_2 to minimize UV loss and ozone formation. Samples are placed on temperature-controlled tables and can variably be irradiated in the beam spot

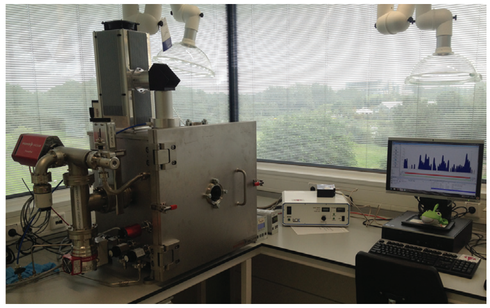

Figure 5.2 The Planetary Analogues Laboratory for Light, Atmosphere and Surface Simulations, Utrecht University.

of the UV source. The temperature of the sample tables is controlled using a refrigerated heating circulator. Three gas inlet valves are connected to the chamber to insert atmospheric gases. One inlet is connected to a N_2 line, used to vent the chamber while preventing atmospheric water from entering. Gases can be either premixed or mixed inside the chamber to obtain the desired atmospheric conditions. Atmospheric pressures inside the chamber are monitored with a pressure gauge [1].

5.3 Mars Wind Tunnels

Dust devils and dust storms occur on a regular basis on the Martian surface, leading to a range of processes. The abrading effect of dust on landers and rovers is one important process, albeit more more engineering than astrobiology. More interesting from an astrobiological perspective are the effects of dust abrasion on mineralogy [7] and the generation of an electric field by dust interaction, a process detected in terrestrial dust storms (e.g., [8]). Martian dust storms have furthermore been related to oxygen enhancement [9] and methane destruction in the atmosphere [10]. A selection of wind tunnel facilities is described below.

5.3.1 The Planetary Aeolian Laboratory (PAL), NASA Ames Research Center, Moffett Field, CA, USA

PAL (Figure 5.3) is a pentagon-shaped, concrete chamber 30 m high, with a floor area of 164 m^2 and a total chamber volume of 4,058 m^3. The entire chamber can be evacuated to a minimum pressure of 3.8 mbar. A 7.6 m × 7.9 m

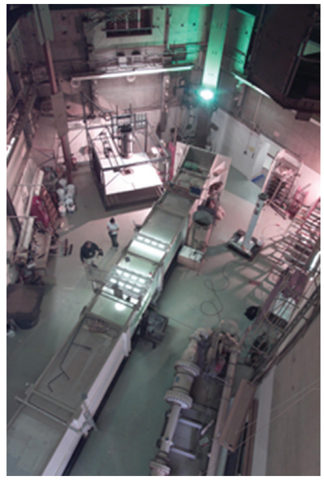

Figure 5.3 The Planetary Aeolian Laboratory. *Image credit* NASA Ames Research Center.

door permits large experimental apparatus to be placed inside the chamber. PAL contains three separate facilities: the Venus Wind Tunnel [11, 12], the Arizona State University Vortex Generator (see below), and the *Mars Surface Wind Tunnel (MARSWIT)*, the first Mars wind tunnel, established in the 1960s at NASA Ames Research Center [13–16]. MARSWIT occupies the center of the PAL with an overall length of 14 m. The tunnel walls are constructed of 2.4-cm-thick clear Plexiglas to enabling ready viewing, and a 1.1-m^2 test section is located 5 m from the entrance. The tunnel is driven by a network ejector system consisting of 72 equally spaced 1.6-m nozzles located in the diffuser section. High-pressure air (up to 9.86 kg/cm^2) is forced through the nozzles to induce flow of air through the tunnel. The maximum attainable free stream airspeed is 13 m/s at atmospheric pressure, increasing to 180 m/s at 5 mbar (500 Pa) [17].

5.3.2 The Arizona State University Vortex Generator (ASUVG), Moffett Field, CA, USA

The ASUVG was built to simulate dust devils in the laboratory and consists of three components. The *vortex generator* includes a cylinder (45 cm in diameter by 1.3 m long) with a “bell mouth” to alleviate boundary effects at the edge of the cylinder, a motor drive, and a fan blade system. To vary the geometry of the simulated dust devil, the generator is mounted to *a frame* so that it can be lowered or raised above the test table. The *table* is 2.4 by

2.4 m, mounted independent of the frame so that potential motor vibrations are isolated from the test bed. The table can be raised or lowered, moved laterally to simulate motion of a dust devil across terrain features, and tilted to simulate a vortex that is not perpendicular to the surface. The facility is equipped with instruments enabling real-time measurements of the ambient temperature, relative humidity, and wind speeds and surface pressures on the test bed beneath the vortex. The generator can be dismantled for, for example, transport into the field for conducting experiments on natural surfaces and use in the MARSWIT for tests under Martian atmospheric conditions [15, 16, 18, 19].

5.3.3 The Aarhus Wind Tunnel Simulator (AWTS), Aarhus, Denmark

The AWTS (Figure 5.4) consists of a recirculating wind tunnel housed inside an environmental chamber and is designed to reproduce the environmental conditions observed at the surface of Mars, specifically the atmospheric pressure and composition, the temperature, wind conditions, and the transport of airborne dust. The environmental chamber is 0.8 m wide and 3 m long and can be evacuated to around 0.03 mbar and repressurized and held at Mars-like pressures (typically 6–10 mbar). The central wind tunnel is cylindrical, 0.4 m in diameter, and 1.5 m long. To maximize the available open wind tunnel area (cross section) while maintaining smooth fluid flow, an axially mounted fan driven by an electric motor draws gas down the central wind tunnel and returns it in an outer cylindrical cavity. Mechanical obstructions that may create excessive turbulence are avoided, and smooth surfaces are used wherever possible [7, 20–24].

Figure 5.4 The Aarhus wind tunnel simulator. *Image credit* Mars Simulation Laboratory, Aarhus University.

5.4 Instrument Testing Facilities

To test planetary instruments under realistic conditions, several chambers have been developed specifically for instrument testing. These facilities mimic planetary conditions as well, but are in general not used for science, but solely for instrument testing.

5.4.1 ChemCam Environmental Chamber

The ChemCam environmental chamber was developed at the University of Toulouse, France, to reproduce the Martian environment to test the first laser-induced breakdown spectroscopy instrument sent into space as part of ChemCam on the Curiosity Rover [25]. The chamber has a volume of 70 l. The chamber is pumped to 10^{-3} mbar and then filled with 95.7 % CO_2, 2.7 % N_2, and 1.6 % Ar to mimic the Martian atmosphere. In each experiment, five samples are placed in the chamber and the ChemCam instrument is installed 3 m from the sample. The chamber is kept at room temperature, which is a difference compared to flight mode conditions, but this should be generally of no importance for laser-induced breakdown spectroscopy (LIBS) analysis because of the high temperature of the plasma ~8,000 °C [26].

5.4.2 SAM Environmental Chamber

The Sample Analysis at Mars instrument suite (SAM) environmental chamber (Figure 5.5) was developed at NASA Goddard Space Flight Center to carry out both thermal testing and qualification and calibration in an environment that could simulate the thermal conditions in the rover on the surface of Mars. The design of the chamber enables simultaneous instrument suite qualification, through thermal cycling, and calibration, utilizing both solid samples and atmospheric samples introduced into SAM through chamber feedthroughs from a gas processing system external to the chamber. The SAM chamber is a ~91 cm electro-polished stainless steel cube fitted with an internal thermal shroud, with an internal test volume of 66 × 56 × 41 cm. This volume consists of six independent thermal zones, where the temperature can be cycled between 233 and 323 K. The pressure in the chamber can be varied from 10^{-6} to 1,000 mbar. The Mars chamber is equipped with a dedicated 120-channel thermocouple data acquisition system and standard contamination control and monitoring systems to include a thermoelectric quartz crystal microbalance (TQCM), residual gas analyzer (RGA) and scavenger plate [27].

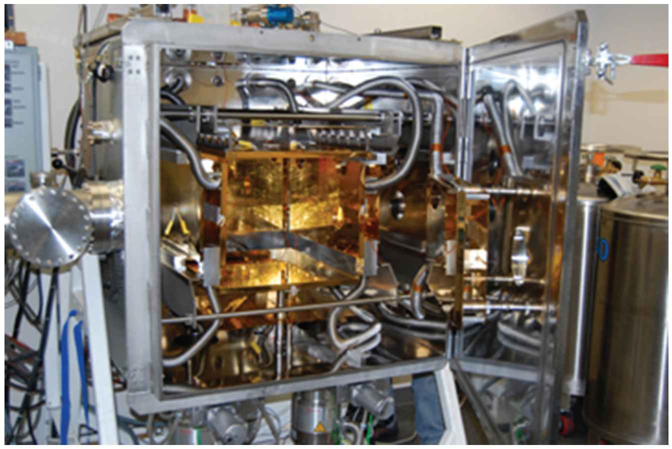

Figure 5.5 The SAM environmental chamber. *Image credit* NASA Goddard Space Flight Center.

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