ELECTRICAL PROPERTIES OF THE SURFACE LAYERS OF MARS

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Abstract. The electrical properties of returned lunar samples when measured in high vacuum conditions have confirmed that the lunar regolith is an excellent electrical insulator, and that it is relatively transparent to radio waves. It is shown in this paper that the observed Martian surface pressures, temperatures, and water contents are consistent with a model of the planetary surface which is electrically similar to that of the moon. The amounts of moisture present are low enough, that they could be adsorbed as a monolayer on the surface of soil grains in the upper few centimeters. The electrical properties of material which has an adsorbed monolayer of water are virtually indistinguishable from completely dry material.

Lunar Observations

Reviews of the electrical properties of the lunar surface as they were understood before the lunar missions are available in several places (Hagfors, 1970; Piddington and Minnett, 1949; Strangway, 1969; Salisbury and Glaser, 1964). Radar reflections showed that the surface had a dielectric constant in the general range of 3 (Hagfors and Evans, 1968; Tyler and Howard, 1973), a clear indication of a highly porous soil. Studies on returned lunar samples as measured in high vacuum and measurements of reflected radio waves from lunar orbiting vehicles confirm a dielectric constant for the soil in the range 2.0 to 4.0 depending upon the packing fraction (Frisillo et al., 1974; Gold et al., 1973).

Microwave emission (> 10 cm) studies showed that there is almost no temperature variation during lunations or eclipses, inferring that most of the energy comes from the subsurface where the temperature is constant (Muhleman, 1972). From this, it is inferred that the lunar surface is relatively transparent to radio waves and is therefore much like a typical dielectric material. The DC conductivity must be very low, and there must not be enough moisture present to cause microwave adsorption. Lunar sample studies have supported these observations. DC conductivities on the order of 10^{-14} to 10^{-16} mho/m are measured in high vacuum at room temperature, and loss tangents are generally less than 0.005 (Strangway et al., 1972; Olhoeft et al., 1973; Bassett and Shackleford, 1972; Gold et al., 1973). These numbers are in good agreement with those predicted before the lunar missions.

Effects of Atmosphere

The essential differences between the moon and Mars lie in the effects of atmosphere, particularly moisture in the atmosphere. The effect of gases on the electrical properties of soils has been examined by several workers (McIntosh, 1966) and with the exception of water, the effect is negligible. Simply exposing lunar samples to air with 30% humidity has been found to increase the DC conductivity by several orders of magnitude, to increase the dielectric constant by up to a factor of 10, and to increase the loss tangent by factors of 10 or more (Strangway et al., 1972). These latter effects are particularly pronounced below 10^5 Hz.

Recent models of the electrical properties of soils (Von Ebert and Langhammer, 1961; Hoekstra and Delaney, 1974) indicate that the polar water molecule in quantities less than one monolayer, becomes so strongly adsorbed onto grain surfaces, that it does not participate in electrical or other transport phenomena. When the water content increases beyond one monolayer, however, molecules are less tightly bonded and they tend to behave much like the molecules in ice, altering the interfacial characteristics and the overall bulk electrical properties. As the water content increases beyond about 7 adsorbed layers, the electrical properties become dominated by pore conduction processes like those in terrestrial soils (Figure 1).

Investigations on lunar soil samples show that they have specific surface areas of 0.3 to 0.6 m^2/gm (Cadenhead et al., 1972, 1973; Holmes et al., 1973). Thus lunar soils containing up to about 0.02% by weight water would have electrical properties identical to those of dry materials at room temperature.

Mars Observations and Predictions

Recent observations of Mars by Mariner 9, infer that the total atmospheric water content reaches a seasonal high of 10 to 30 microns.

MOON	MARS		EARTH
solid	monolayer -electrically transparent	2-7 layers -low frequency polarization	free pore water 7 + layers -strong microwave absorption
0.3 m^2/gm*		0.02 wt%	0.14 wt% water**
K' = ~2-4*		~5-15	~15+**
K"/K'= ~0.001*		~0.01	~0.1+

* depending somewhat upon packing and material composition in soil

** depending upon frequency (0.14 % H_2O produces K' = 15 at 10^5 Hz, but larger amounts are required at higher frequencies)

Figure 1 Schematic illustration of the effect of water on the electrical properties of soils.

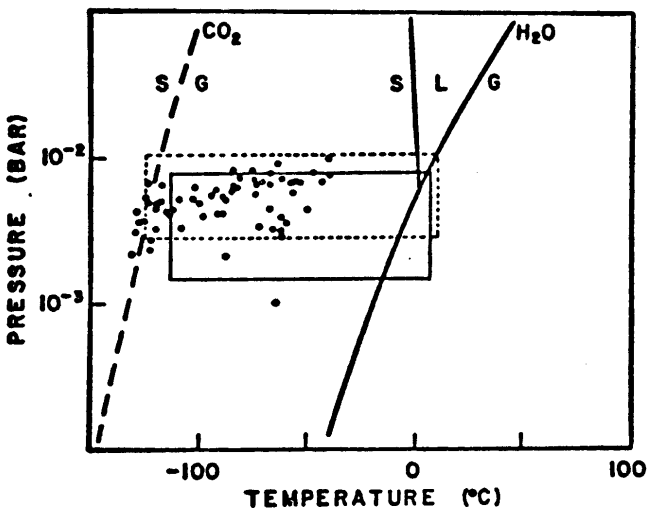

Figure 2 Pressure temperature diagram illustrating the range of surface temperatures and pressures on Mars. (See text for key.)

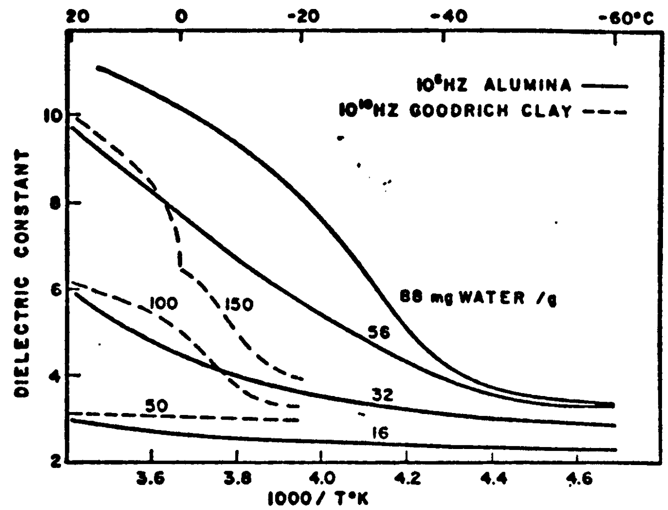

Figure 3 Dielectric constant in powder Al_2O_3 (after Von Ebert and Langhammer, 1961) and Goodrich clay (after Hoekstra and Delaney, 1974) versus water content (mg Water/gm) at various temperatures.

Figure 2 shows the surface pressure-temperature regime from the S-band occultation experiment (circles and dashed box) by Kliore et al. (1973), the pressure range (solid box ordinate) from the IR spectrometer experiment by Conrath et al. (1973), and the temperature range (solid box abcissa) from the IR radiometer experiment by Kieffer et al. (1973).

Assuming the surface material on Mars has specific surface areas like those of the lunar surface, 30 microns of water could distribute itself in a monolayer in the upper 5 to 10 cm of soil while a clay like material could adsorb a similar amount of water in fractions of a millimeter. As such, the atmospheric moisture would have no influence on the electrical properties at room temperature. Thus, the surface of Mars would behave electrically like a dry, insulating dielectric material very much resembling the lunar surface.

If there are larger quantities of water or ice trapped in the upper layers (Sharp, 1973), the effect of temperature also needs to be considered. Figure 3 illustrates the effects of temperature with varying moisture content on the dielectric constant of a powder-alumina (after Von Ebert and Langhammer, 1961) and a clay (after Hoekstra and Delaney, 1974). It may be readily seen that at the Martian mean equatorial temperature of -60°C, even large amounts of water (up to 10 wt %) cause only small changes in the dielectric constant (and loss tangents at high frequencies). Thus, Mars is expected to be an insulating dielectric and should depart from this only in regions of anomalously high localized water at high temperatures.

These observations are in good agreement with Mariner 9 and Earth-based observations. Initial Earth-based radar results indicated a mean dielectric constant of 3.5 (Pettengill et al., 1969; Rogers et al., 1970) while more recent studies by Pettengill et al., 1973 suggest that the dielectric constant varies between 1.7 and 5.0, with fairly wide error limits. In addition, Marov and Petrov (1973) report that the Soviet Mars 2 and 3 missions saw several hot spots 10-15° warmer than neighboring areas, where a simultaneous increase of the dielectric constant occurred from 2 to 5. This could be the effect of a dense soil or a solid, or it could be the effect of a higher temperature, high water content soil as suggested by the response in Figure 3. Microwave emission temperatures have been measured by a number of workers over the range from 0.1 to 21.3 cm wavelengths and found to be nearly constant. The implications for Martian surface properties have been reviewed by Epstein (1971), by Sagan and Veverka (1971), and by Cuzzi and Muhleman (1972). Cuzzi and Muhleman have interpreted the results as being consistent with a dielectric sphere with an effective dielectric constant of 2.5 and a loss tangent (<0.01) much like that reported from lunar observations.

Summary

Although more detailed observations of Mars are required, it seems likely that the electrical properties of the Martian surface are very similar to lunar surface materials. This is quite unexpected, since the presence of moisture had been expected to have an important influence. It is shown, however, that surface concentrations of water up to 0.02 wt. % (or higher amounts in clays) below -60°C, cause little change in the material electrical properties beyond that found in dry insulators.

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