THE MEASURED PERMITTIVITY OF CO₂ ICE GROWN UNDER MARTIAN POLAR CONDITIONS
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Introduction: The relative electric permittivity, \( \varepsilon_r \), of dense carbon dioxide ice has been measured, with the ice being formed directly from its gas at temperatures around 130 K under 1 mbar of pressure. At 1 kHz \( \varepsilon_r \) is 4.6 ± 0.2 and at 100 Hz \( \varepsilon_r \) takes a value of 5 ± 1. There appears to be no data in the literature for this near-DC property of CO₂ ice, especially for ice grown from the vapour phase at temperatures comparable to those at the surface of the Martian poles. Experiments at frequencies similar to those used by Ground Penetrating Radar (GPR) will be useful for future spacecraft missions aiming to reveal the stratigraphy and burial depth of Martian polar materials such as water ice.

GPR to come: The European Space Agency (ESA) spacecraft, Mars Express, will employ a radar science experiment during its mission. This package is designed to be capable of detecting strong discontinuities in the electromagnetic impedance of the Martian near-surface at depths of several hundred metres. Models of the electromagnetic properties of potential Martian sub-surface components, such as water ice and various rock types, have been studied [1] using laboratory measurements of the permittivity values for these analogues.

One such material has, however, not been considered in these experiments. Although CO₂ snows\(^1\) made by manual compaction have had their \( \varepsilon_r \) values measured [2] at various bulk densities, there appear to be no data for \( \varepsilon_r \) of void-free ice grown from CO₂ gas under the low pressures and temperatures found in the Martian polar winters. This form of solid CO₂, in contrast to rapidly condensed snows, could be a close analogue for the major component of the seasonal Martian icecaps. Accurate measurements of this substance’s dielectric properties will be needed when Martian GPR data are processed.

Formation: A dedicated vacuum chamber has been built at the PSSRI for the study of the mechanical properties of cryogenic ices. This chamber, equipped with an instrumented drilling system, can condense ices from the vapour phase into a liquid-nitrogen cooled sample holder. Temperature measurements are made with small Pt 100 thermometer elements and the sample holder can be fitted with a mesh-plate capacitor, shown in the following figure.

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\(^1\) Source snow being made by the rapid expansion of pressurized CO₂ gas through a flow constriction.

Figure 1. A small air-gap capacitor with a nominal capacitance of 16 pF.

CO₂ growth. In contrast to the many geometries that may be displayed when forming water ice from its vapour [3], carbon dioxide shows a simpler set of ‘habits’. The bi-pyramidal microstructure seen [4 and 5] when condensing the gas on a cryogenically cooled substrate is continued at larger scales, with 0.1 mm facets being easily seen in the growth of CO₂ ices. This ‘randomly-glued-salt-grain’ topology rapidly infills itself to form a smooth compact mass and is seen to form on cold surfaces away from the direct path of the admitted gas. Directly in the flow of the CO₂, the ice takes on the smooth, almost glossy, compact form more rapidly.

Analysis: The sensor was cleaned before and after its use in the vacuum system with a regime of acetone and deionised water flushes. In the chart below the total measured capacitance, which includes the stray capacitance of the sensor leads, is shown. Region (A) denotes the progressive covering of the sensor face by CO₂ ice to a depth of around 3 mm, and region (B) shows its emergence when the ice sublimates. Note that data were not taken at equal time intervals.

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Figure 2: The changes in capacitance caused by CO₂ ice growth and decay over the course of ~5 hours.
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A non-polar liquid with known dielectric properties (toluene, grade assayed at >99% purity with < 500ppm water) was used as a calibration medium after the ice-formation experiment. The capacitor was submerged in toluene at room temperature and pressure, and the shift in measured capacitance from its value in air was noted. Care was taken to keep the device’s lead lengths and positions mostly unchanged from their earlier arrangement in the vacuum chamber.

A figure of 2.391 [6] was used for the value of toluene’s \( \varepsilon_r \) at 20°C and from this the permittivity of CO₂ ice could be inferred by comparing the capacitance shift from air to CO₂ with the corresponding change from air to toluene. Measurements were made at two frequencies, 100 Hz and 1 kHz using an AVO B184 LCR analyzer. Despite the more imprecise readings made in the 100 Hz range, two phenomena seen by previous workers [2] are supported. The values of \( \varepsilon_r \) for CO₂ ice do not appear to be strongly frequency dependent. Furthermore, the temperature sensitivity is also very small - this work fills the gaps between the two measurements at 113 K and 183 K of [2] made at higher frequencies.

Discussion: GPR models for Martian system architectures have used figures from 1.7 [2] to 3 [7] for the \( \varepsilon_r \) of dense CO₂. Viking orbiter radar data for regions of the Martian North pole suggest a surface \( \varepsilon_r \) of 1.5 [8]. The value of \( \varepsilon_r \), inferred in this work from a calibration liquid, for vapour-grown dense CO₂ is larger than that predicted or presumed by previous studies. If correct, this value for solid CO₂’s permittivity alters the signal budget for a GPR system. The return signal’s strength is proportional to \( \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \) for media of \( \varepsilon_1 \) and \( \varepsilon_2 \). Thus, the backscattered echo from a plane water ice/CO₂ ice layer may be 0.1 of the input power in contrast to zero for media of the same \( \varepsilon_r \).

The extra returned power from this higher-than-expected dielectric contrast may yet be of marginal interest as surface backscatter from topography and buried features rough at the system wavelength can readily dominate radar echo strength. However, in trying to constrain the thickness of a CO₂ layer by echo-delay measurement from underlying discontinuities, the absolute permittivity of the material must be known. It is suggested that ice grown from the vapour phase should continue to be studied at more appropriate radar-like frequencies if the burial depth of polar features such as permanent water ice caps or permafrost is to be established with accuracy.


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