ELECTRICAL PROPERTIES OF CO_2 CLATHRATE TO UNDERSTAND RADAR SIGNALS FROM FUTURE MISSIONS TO THE JOVIAN MOONS.

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Introduction: Galileo mission found evidences of the presence of a global ocean and/or liquid water reservoirs under the ice surface of Europa and Ganymede [1], but the specific location of the aqueous environments is still a mystery. The JUICE (ESA) and Europa Clipper (NASA) missions will try to determine the internal structure of these Jovian icy moons subsurface with the radar instruments onboard: RIME and REASON, respectively. Both produce radio signals of 9 MHz that are able to penetrate down to 9 and 30 km depth, in each case.

The composition of the moons' crust could include gas clathrates as was proposed in references [2, 3]. Clathrate hydrates dissociation could be related to some geological activity, for example the formation of the transitory jets on the surface of Europa, as detected by the Kent telescope [4, 5].

Although there are a lot of works about clathrates and their general properties, few of them study their electrical properties. References [6, 7] determinate the high frequency permittivity (ε_∞) of several clathrates, finding a value of 2.85 at 233 K for clathrates including simple guest molecules such as argon and nitrogen, that increases over 7.7 in more complex guest molecules such as ethylene oxide and acetone. Up to our knowledge, [8] is the only work about the CO_2 clathrate. In that paper the authors provide the conductivity value of both CO_2 and CH_4 clathrates, but they did not show the permittivity.

In order to better recognize the radar signals and to detect if these compounds exist in Europa, we need to understand their electrical properties. In this work we present novel results for CO_2 clathrate including a combined conductivity and permittivity study.

Methodology: We use a stainless-steel high pressure chamber with an internal volume of 60 ml for the formation of clathrate hydrates. In this cell we mixed distillated water with CO_2 gas at 30 bar of pressure.

The conditions of temperature and pressure are recorded at fixed time intervals by sensors inserted into the cell during all the testing. For the electrical measurements we used a Teflon cell inside the pressure chamber with two polished stainless steel electrodes. Data were taken in isothermal conditions, stabilizing the sample during 10 minutes at each temperature step, when the conductance (G) and parallel capacitance (Cp) were measured, in the frequency range from 20 Hz to 10^6 Hz in several steps using an LCR precision meter (Agilent HP4284A).

The electrical measurements were taken at different temperatures in the boundaries of the clathrate CO_2 stabilization phases, following the phase diagram H_2O-CO_2. To ensure the phase formed at each temperature range, we performed *in situ* Raman spectroscopy through the sapphire window of the chamber.

Results: We determined the electrical conductivity and real permittivity values for samples of CO_2 clathrate and water with CO_2.

When CO_2 clathrate is formed, the electrical characterization show a constant conductivity *vs.* frequency (Fig. 1, A), with a very small temperature variation. The real part of the permittivity (Fig. 2, A) show at high frequencies (above 100 kHz) a value of $\varepsilon_\infty = 2.5$, and a $\sigma = 1.5\ 10^{-6}$ S/cm, both at 255 K, in agreement with reference [8].

The conductivity (Fig. 1, B) and real permittivity (Fig. 2, B) curves of the sample H_2O+CO_2 with no clathrate formation show a steeper dependence with the frequency and temperature in comparison with the CO_2 clathrate.

The attenuation of the signal was calculated with the experimental values of conductivity and real permittivity (Eq. 1) [9] at 10 kHz (Fig. 3).

$$\alpha \cong \sigma/(2c\varepsilon_0 \sqrt{\varepsilon'} \qquad \text{(Eq. 1)}$$

Interestingly, we observe that the attenuation of H_2O+CO_2 with no clathrate formation and the CO_2 clathrate have great differences. When the CO_2 clathrate is formed, the value of attenuation is one order of magnitude higher than the phase of H_2O+CO_2 (when clathrate is not formed). These differences could be the key to differentiate between precursor phases and clathrate in radar studies of Jovian moons.

Conclusions: The studied samples have substantial differences in their electrical properties, which would allow us to differentiate them in radar measurements. The possible relation with surface morphological features could help to understand the geological activity of the moons, such as the mechanism of jets formation proposed for Europa.

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References: [1] Kivelson, M. G. et al. 2000, Science, 289, 1340-1343. [2] Hand, K. et al 2006, Astrobiology Vol 6, 3. 463-482. [3] Prieto-Ballesteros, O. et al. Icarus, 177, 491-505. [4] Paganini, L et al. 2019, Nature Astronomy, 4, 266-272. [5] Shiblev, N.C. & Laughlin G., 2021, The Planetary Science Journal, 2, 221. [6] Davidson, D.W. 1973 The Physical Chemistry of Water Vol2 115-234. [7] Davidson D.W. & Ripmeester J.A. Journal of Glaciology, 21, 33-49. [8] Stern L. A. et al. 2021, Geophysical Research Letters, 48. [9] Petinelli et. al 2015. Reviews of Geophysics 53, 593-641.

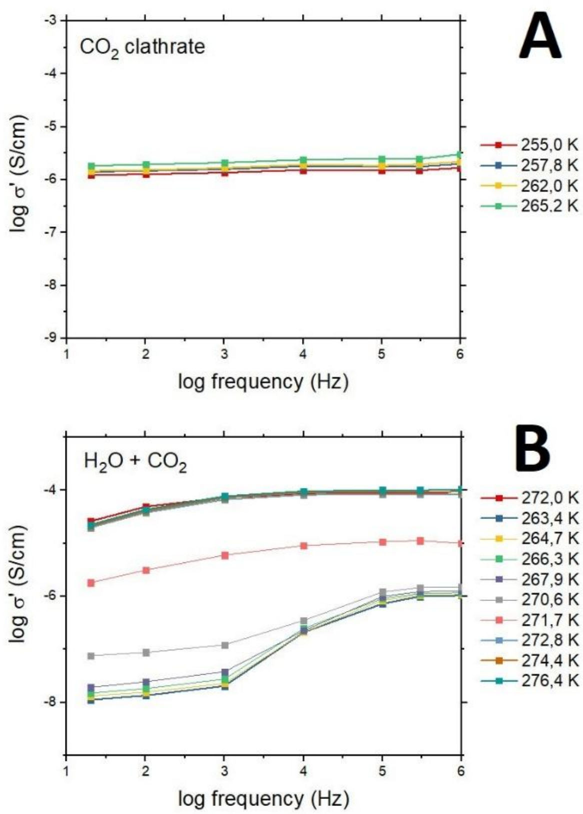

Figure 1: Electrical conductivity of CO_2 clathrate (A), and water with CO_2 (B).

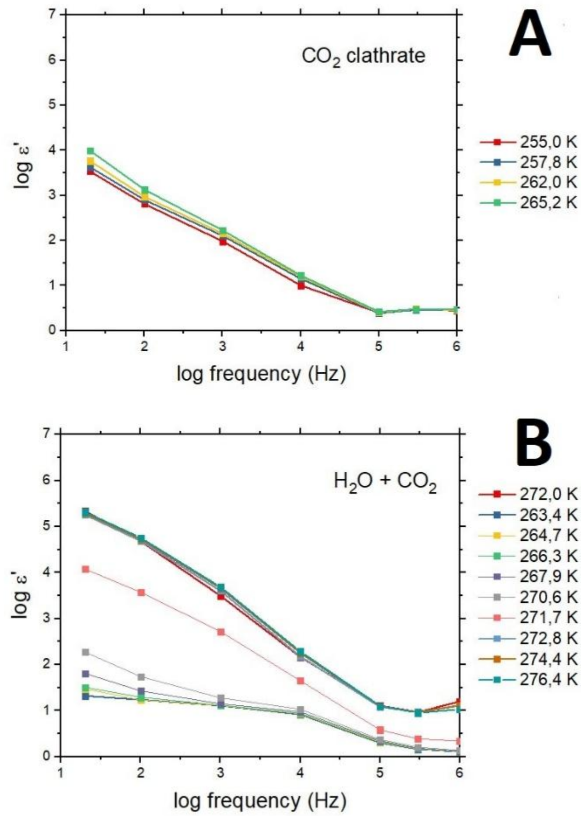

Figure 2: Real permittivity of CO_2 clathrate (A), and water with CO_2 (B).

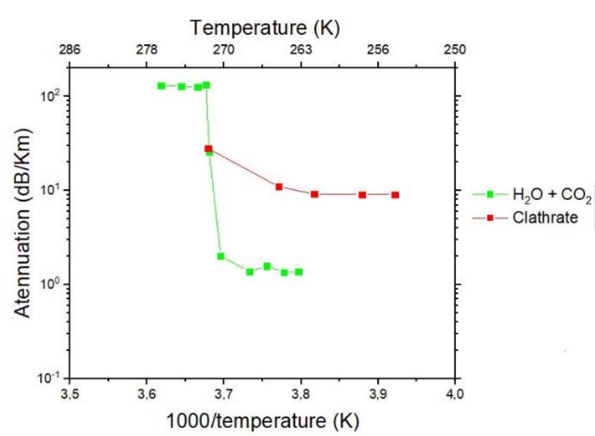

Figure 3: Attenuation of the samples at 10 kHz.