Reports

Lunar Permafrost: Dielectric Identification

Abstract. *A simulator of lunar permafrost at 100°K exhibits a dielectric relaxation centered at approximately 300 hertz. If permafrost exists in the moon between 100° and 213°K it should present a relaxation peak at approximately 300 hertz. For temperatures up to 263°K it may go up to 20 kilohertz.*

The controversy over the existence of water in the moon (*1*) will have an "in-depth" test when the electromagnetic soundings made during Apollo 17 have been analyzed (*2*). The results of those experiments will have to be interpreted in terms of models of the lunar regolith and its dielectric properties.

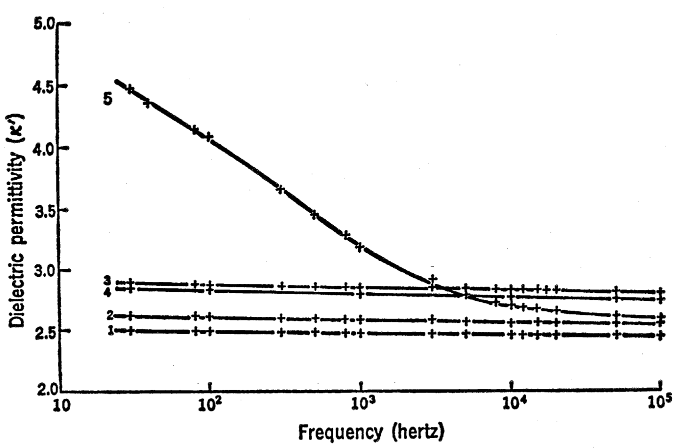
Permafrost is one of the two possible modes of existence of water in the moon, the other being liquid water. Models of the internal constitution of the moon in which the existence of H_2O is considered concur in locating the permafrost layer above the liquid water (*3, 4*). The depth and extent of the permafrost layer is a matter of speculation. If we assume that such models are valid, electromagnetic signals would have to travel through permafrost before detecting liquid water.

Information on the dielectric properties of lunar samples is available at various frequency ranges and temperatures (*5, 6*). However, little is known about the role of frozen moisture in the dielectric behavior of these samples at temperatures below 273°K. The interpretation of the lunar electromagnetic soundings, on the basis of the data presently available, may thus leave ambiguities regarding the presence of the permafrost layer. This report provides information on the typical response to electromagnetic excitations that may be expected from a permafrost layer in the moon.

Measurements of the dielectric permittivity (κ') and loss tangent ($\tan \delta$) of a lunar simulator (*7*) have been carried out in the frequency range of 30 to 10^5 hertz, at temperatures varying from 100° to 373°K and vacuums of around 7.0×10^{-8} torr, in an attempt to simulate conditions in the upper layers of the lunar regolith. A specially designed guarded-electrode system was used. Complete results of these experiments will be presented elsewhere (*8*). Here I shall restrict the discussion to the responses at 100°K.

In order to establish a basis of reference (*9*), I measured samples of the lunar simulator with packing densities of 1.80, 2.00, and 2.20 g/cm³ containing initially atmospheric moisture (at 40 percent relative humidity). Before they were cooled to 100°K the samples were maintained at room temperature and 5.0×10^{-8} torr for periods of 2 to 3 hours, so that part of their initial moisture content was released. In Figs. 1 and 2 the values of κ' and $\tan \delta$ for the samples at 100°K and 7.0×10^{-8} torr are plotted. Curves 1, 2, and 3 correspond to the densities cited above. Curves 4 (Figs. 1 and 2) were obtained for the sample of density 2.20 g/cm³ after a cycle of heating (to 373°K) and cooling (to 100°K) took place in the high vacuum. The differences with respect to curves 3 are due to additional water losses occurring at the higher temperature. This result is in agreement with observations made of repeated heating and cooling cycles at other temperatures (*8*). Curves 1 through 4, for $\tan \delta$, present broad maxima between 100 and 300 hertz, while the corresponding κ' curves decrease slowly with increasing frequency.

The sample that yielded curves 4 was used to prepare a new sample of density 1.90 g/cm³, consisting of the lunar simulator (87.7 percent by weight) and distilled H_2O (12.3 percent). The sample had a doughy texture. At 100°K and 7.0×10^{-8} torr, the values obtained for



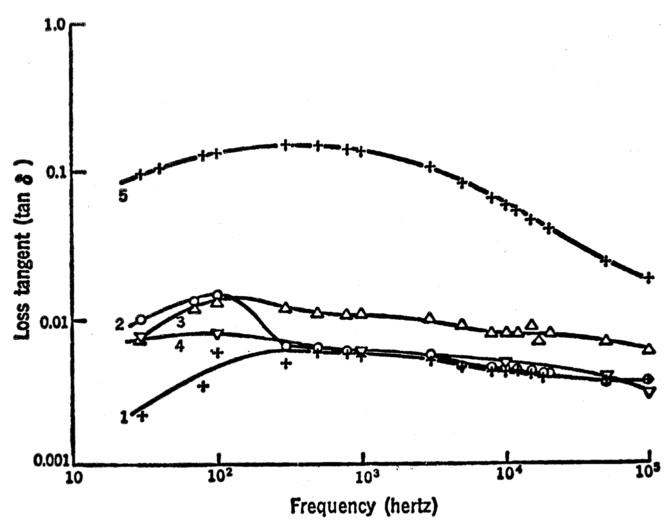


Fig. 1 (left). Dielectric permittivity (relative) of the lunar simulator at 100°K and 7.0×10^{-8} torr, plotted against frequency. Fig. 2 (right). Loss tangent of the lunar simulator at 100°K and 7.0×10^{-8} torr, plotted against frequency. Refer to the text for an explanation of the curve numbers.

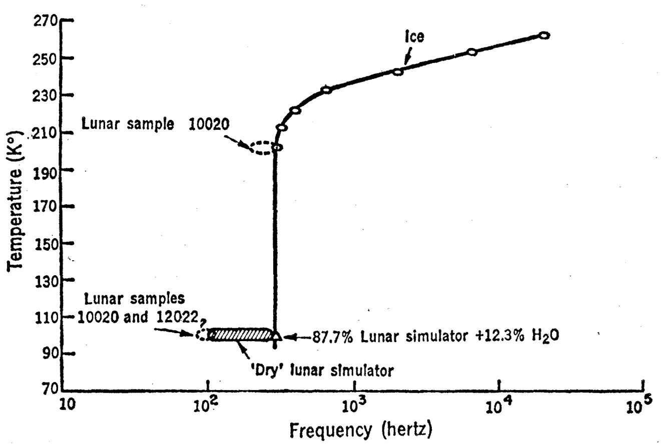


Fig. 3. Temperature plotted against the frequency at which the peaks of dielectric relaxation occur for ice (*12*), lunar simulator plus water, "dry" lunar simulator, and two lunar samples (*5*).

κ' and tan δ are shown as curves 5 (Figs. 1 and 2). If the same data are plotted as κ'' against κ' ($\kappa'' = \kappa'$ tan δ), they correspond to a Cole-Cole distribution (*10*) given by

$$\kappa^* = \kappa_\infty' + \frac{\kappa_0' - \kappa_\infty'}{1 + (j\omega\tau)^{1-\alpha}} \qquad (1)$$

with $\kappa_0' = 4.90$, $\kappa_\infty' = 2.57$, $\tau = 6.5 \times 10^{-4}$ second, and $\alpha = .39$. The symbol κ^* denotes the complex (relative) dielectric permittivity, κ_0' and κ_∞' are the values of the real part of κ^* at zero and infinite frequency. The imaginary part of κ^* is κ'', $j = (-1)^{1/2}$, ω is 2π times the frequency, τ is the generalized relaxation time, and α is a parameter that can vary between 0 and 1.

These results show that with increasing amounts of moisture the dielectric behavior of the sample, in the frequency range of 30 to 10^5 hetrz and at 100°K, eventually becomes dominated by ice. The broad peaks observed in curves 1 through 4 (Fig. 2) are interpreted as relaxations occurring in the frozen moisture remaining in the sample. The corresponding κ' curves are in agreement with the existence of such relaxations. However, the small κ' increments with decreasing frequency preclude its consideration as positive evidence. The vapor pressure of ice at 120°K has been estimated as 1.4×10^{-12} torr (*11*); therefore, the amount of water frozen at 100°K and 7.0×10^{-8} torr will remain in the sample as long as such conditions are maintained in the laboratory. Curves 3, 4, and 5 (Fig. 2) qualitatively establish that the sample losses are proportional to their ice contents. A quantitative evaluation of the amount of frozen moisture and its effect on κ' and κ'' is presently under way (*8*).

The existence of lunar permafrost is expected within the temperature range of 100° to 273°K (*4*). The results presented here represent the lower temperature limit. It is known that the relaxation peak for ice moves toward lower frequencies when the temperature decreases (*12*). In Fig. 3 I have plotted the ice temperature against the frequency at which the peak of the relaxation occurs. The ellipses represent data for ice (*12*); the triangle corresponds to the peak in curve 5 (Fig. 2). Extrapolation of the results for ice is in agreement with my results at 100°K.

Lunar samples 10020 and 12022 were contaminated by atmospheric moisture when the dielectric measurements were performed (*5*). Consequently, relaxation phenomena associated with the frozen contaminating water should be expected. The peaks observed for tan δ in those measurements have been incorporated in Fig. 3. The question mark by the lunar samples at 100°K indicates the possibility of the peak occurring at slightly lower frequencies.

In conclusion the evidence presented indicates that if permafrost exists in the moon between 100° and 213°K it will have a dielectric relaxation peak at approximately 300 hertz. If its temperature is between 213° and 263°K the relaxation peak will occur between 300 hertz and 20 khz. The frequency at which the relaxation maximum occurs may serve as a crude thermometer.

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References and Notes

1. T. Gold, in *The Nature of the Lunar Surface*, W. N. Hess, D. H. Menzel, J. A. O'Keefe, Eds. (Johns Hopkins Press, Baltimore, 1966), p. 1→ H. C. Urey, *Nature* **216**, 1094 (1967).
2. E. Driscoll, *Sci. News* **102**, 268 (1972).
3. S. H. Ward, G. R. Jiracek, W. I. Linlor, *IEEE Trans. Geosci. Electron.* **7**, 19 (1969).
4. D. H. Chung, *Moon*, in press.
5. ——, W. B. Westphal, G. Simmons, *J. Geophys. Res.* **75**, 6524 (1970); in *Proceedings of the Second Lunar Science Conference*, A. A. Levinson, Ed. (M.I.T. Press, Cambridge, Mass., 1971), p. 2381.
6. T. J. Katsube and L. S. Collett, in *Proceedings of the Second Lunar Science Conference*, A. A. Levinson, Ed. (M.I.T. Press, Cambridge, Mass., 1971), p. 2367; T. Gold, B. T. O'Leary, M. Campbell, in *ibid.*, p. 2173; T. Gold, M. J. Campbell, B. T. O'Leary, *Science* **167**, 707 (1970).
7. The lunar simulator of core S/N 2013 from Apollo 12 was a terrestrial basalt.
8. R. Alvarez, in preparation.
9. ——, *J. Geophys. Res.*, in press.
10. K. S. Cole and R. H. Cole, *J. Chem. Phys.* **9**, 341 (1941).
11. K. Watson, B. Murray, H. Brown, *J. Geophys. Res.* **66**, 1598 (1961).
12. C. P. Smyth and C. S. Hitchcock, *J. Amer. Chem. Soc.* **54**, 4631 (1932).
13. I thank D. W. Strangway for providing the lunar simulator, H. F. Morrison and M. F. Merriam for discussion of the results, and B. Jain for help in the laboratory. Supported by NASA grant NGR 05-003-447.

16 November 1972

Purine Overproduction in Man Associated with Increased Phosphoribosylpyrophosphate Synthetase Activity

Abstract. *In hemolyzates from red cells of two brothers with purine overproduction and gout, activity of phosphoribosylpyrophosphate synthetase is more than twofold greater than that measured in normal or other gouty individuals. The increased enzyme activity, which is also demonstrable in fibroblasts of the one patient tested, is associated with increased production of 5-phosphoribosyl-1-pyrophosphate by intact cells, an indication that the enzyme abnormality is the basis for the purine overproduction. This genetic abnormality is an example of an increased enzyme activity producing a disease state.*

Excessive purine synthesis de novo contributes to the hyperuricemia of a substantial portion of patients with gout (*1*). Progress has been made in identifying some of the specific biochemical and genetic factors responsible for derangements in this important regulated biosynthetic pathway (*2*). In addition to clarifying clinical syndromes, these studies have shed light on the nature of some of the factors involved in the normal mechanism regulating purine metabolism (*3*). Nonetheless, the derangements now known and associated with excessive purine production can account for only a small proportion of the cases of purine overproduction in man (*1, 4*).

We now report another distinct genetic and biochemical abnormality re-