The Interaction of Lunar Rock and Far Infrared Radiation

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Phil. Trans. R. Soc. Lond. A 1977 **285**, 319-324
doi: 10.1098/rsta.1977.0071

Phil. Trans. R. Soc. Lond. A. **285**, 319–324 (1977) [319]
Printed in Great Britain

The interaction of lunar rock and far infrared radiation

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It is the purpose of this paper to review first those measurements which can be made of the interaction of far infrared radiation with lunar rock and then to discuss the significance of these measurements. The measurements themselves may be made either by observing the radiation mostly thermal, which comes from the lunar surface or subsurface layers; or by laboratory observations of the effect of the interaction of a beam of far infrared radiation with various lunar samples. The interpretations of the measurements can also be subdivided depending on whether they have direct significance for the Moon or more generally for astronomical science.

1. Observations of far infrared properties of lunar rock

This section will describe the measurements which have so far been made of the interaction of far infrared radiation with lunar samples. These measurements have been entirely carried out by the group working at Queen Mary College and this account will form a review of already published work together with some recent and previously unpublished measurements of scattering of radiation. The wavelength range considered is from 300–3000 μm.

The coefficient of attenuation and the coefficient of reflection are two quantities which may be inferred from the direct results of an experiment. These two quantities are related to, and replaced in much theoretical analysis, by the real and imaginary parts of the dielectric constant. Although the latter may seem the more fundamental, there are many instances in which the former set are more convenient. In the case of lunar rock, samples are rarely homogeneous so that reflexion processes may take place at the various interfaces. The problem becomes complex in an assembly of lunar fines in which the surfaces may be only approximately in contact and the particle size may be more, less, or of the same order as the wavelength. Indeed there is a complex relationship between the directly measured quantities and the more theoretically appropriate parameters: the relation between the two will normally depend on a simplified and hence only approximate model of the experimental arrangement. It is for these reasons that this section will consider mainly the immediate results of measurements of the interaction of far infrared radiation with lunar rock, although I shall attempt to distinguish between scattering and true absorption processes.

(*a*) *Absorption measurements*

Figure 1 shows the attenuation coefficient measured for a number of samples of lunar fines using a polarizing interferometer (Martin & Puplett 1969) and a cooled indium antimonide detector. The attenuation coefficient α_λ may be considered to be the sum of a pure absorption coefficient K_λ and a scattering coefficient σ_λ the latter term being important since there are appreciable spaces between the fine particles:

$$\alpha_\lambda = K_\lambda + \sigma_\lambda. \qquad (1)$$

In deducing values of the parameters an allowance was made for reflection losses at both surfaces of the sample. This reflexion loss is clearly sample-dependent and errors in the assumed value may lead to comparatively large errors in the deduced coefficient of attenuation particularly in the case of relatively transparent samples where surface reflexion losses represent an appreciable fraction of the total attenuation. To reduce the effect of this reflexion loss, measurements were made at one particular wavelength 338 μm of a number of samples of different thickness. The source, a cyanogen laser, had an output many orders of magnitude greater than the minimum intensity detectable so that a large variation in sample optical depth was possible. The results shown in figure 2 indicate a relatively exact determination of the coefficient of attenuation at this wavelength.

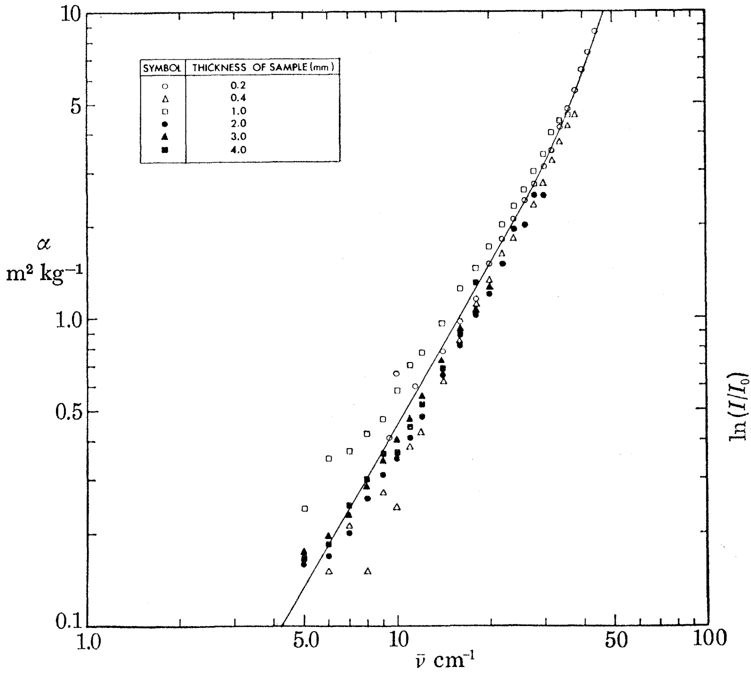

FIGURE 1

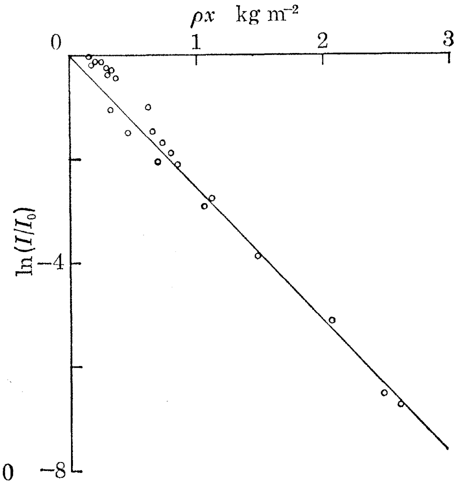

FIGURE 2

FIGURE 1. Attenuation in the range 200–2000 μm for Apollo 11 fines (10084, 111). α represents the absorption coefficient and ν the wave number. Measurements at a given wavelength with different sample thicknesses cover a large range of fractional transmissions. In particular above 1000 μm wavelength, only the thicker samples (solid symbols) can be expected to have appreciable significance.

FIGURE 2. Transmission intensities for lunar fines (Apollo 11 sample 10084, 111) at 338 μm. A cyanogen laser source and Golay pneumatic cell detector were used. This arrangement makes possible a high sensitivity so that samples which reduce the initial intensity by several orders of magnitude can be used, thus reducing the effect of reflexions on the calculated absorption. I and I_0 refer respectively to the intensities before and after transmission through the sample. ρ is the density and x the thickness of the sample.

The distinction between true absorption and scattering is more difficult to deduce. Figure 3 however shows some results of measurement of the absorption coefficient at various temperatures. The coefficient of absorption would be expected to be temperature dependent whilst any scattering would be expected to be virtually temperature independent. For this reason it can be seen that at the higher frequencies, the greater part of the attenuation results from true absorption whereas the reverse is the case at lower frequencies.

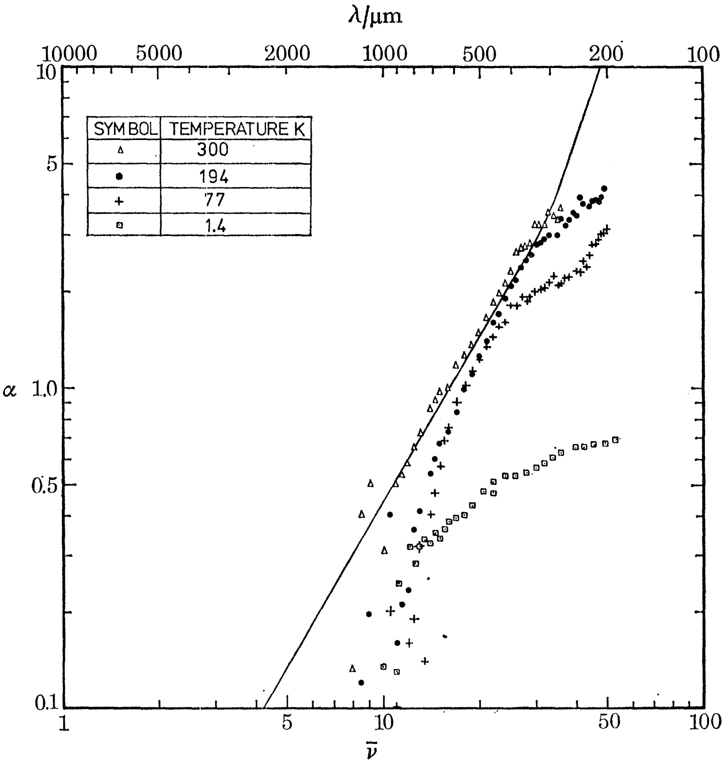

FIGURE 3. Mass attenuation coefficient α for the lunar fines measured with the polarizing interferometer at various temperatures. The continuous curve represents the mean of results reported by Ade *et al.* (1971).

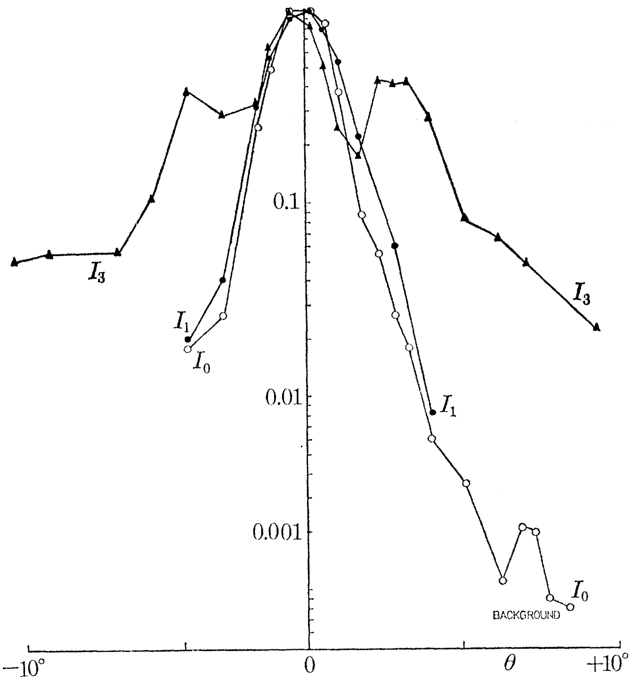

FIGURE 4. Intensity of radiation received through samples for areal densities 0.25 and 0.75 kg m^{-2} and empty sample holder, normalized to unity at the peak. These intensities are labelled as I_1, I_3 and I_0 respectively.

(*b*) *Scattering*

Recently some direct but preliminary measurements have been made which show directly the presence of scattering of far infrared radiation by lunar fines. The results are shown in figure 4. These represent the effect of passing a 338 μm beam through two samples of fines. The results are shown in figure 5 as polar diagrams and from this the scattering is seen to be highly concentrated as forward-angle scattering. The results give a mean scattering coefficient for the fine material at 338 μm of $5.2 \pm 0.5\ \mathrm{m^2\,kg^{-1}}$ for the loosely packed fines whilst the volume albedo, that is the ratio of scattering to total attenuation coefficient, A, is 0.73 ± 0.05. The coefficient of scattering is however highly dependent on the degree of packing, the density in this case being $0.9 \pm 0.2 \times 10^{-3}\ \mathrm{kg\,m^{-3}}$.

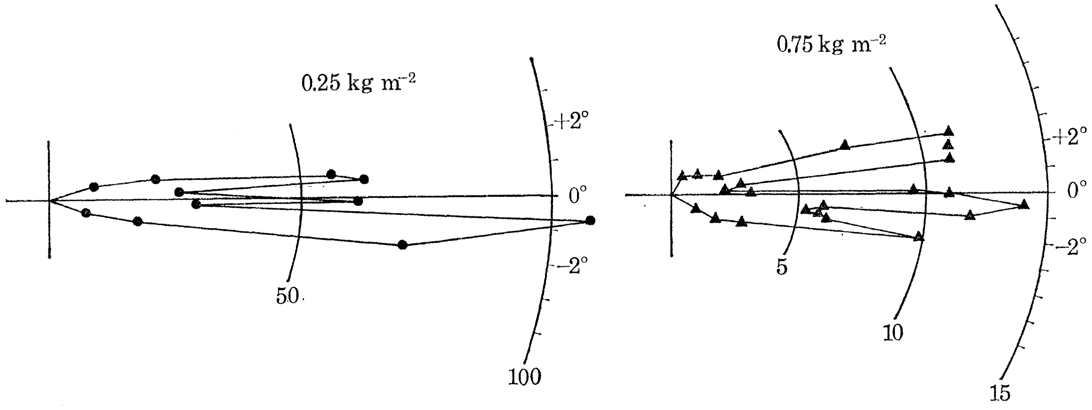

FIGURE 5. Intensity of scattered radiation from samples of areal density 0.25 and 0.75 kg m^{-2}. These intensities are shown on an expanded angular scale.

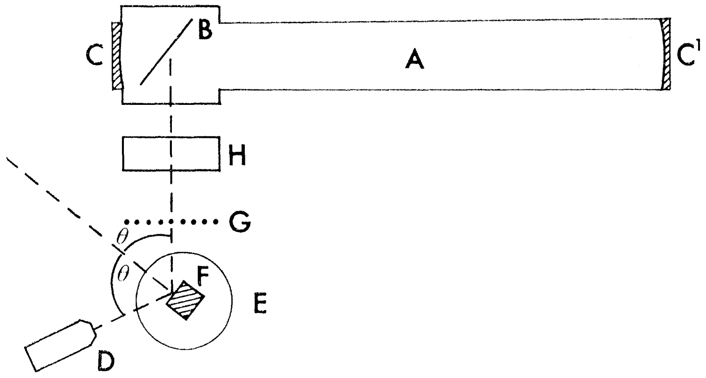

FIGURE 6

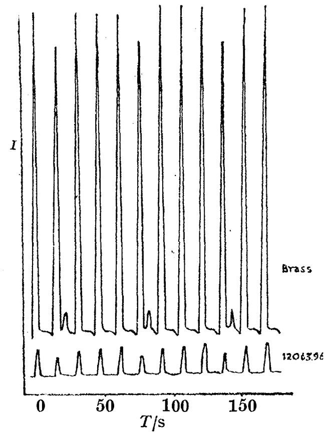

FIGURE 7

FIGURE 6. Determination of reflexion coefficient of lunar sample in block form. A is a cyanogen laser with reflecting mirrors CC′ and beam splitter B. H rotates the beam of polarization by $\frac{1}{2}\pi$ and is present for S-type measurements only. G is a polarizing grid which ensures that the radiation is effectively plane polarized. The block F is placed on the rotating table E and the radiation reflected into the detector D.

FIGURE 7. Pen recording showing reflexion from the block 12063, 96 (type A) and a brass block. The intensity of the reflected beam is shown in the vertical direction, the horizontal axis showing time in seconds. The regular rotation of the sample gives a rotation of the reflected beam, and this intersects the detector giving the regular peaks shown in the figure. The lack in consistency in the reflexion from the lunar block is attributed mainly to surface roughness.

(*c*) *Reflexion*

So far the only measurements which have been made of the far infrared reflexion coefficient is at a single frequency 338 μm. The optical arrangement for these measurements are shown in figure 6. In order to obtain the reflexion coefficient the measurements are carried out first with the same block at *F* and then with a polished block of brass of the same shape. Recordings of the intensity measured by the detector for both metal and sample blocks are shown in figure 7. The coefficient of reflexion was determined as the ratio of the reflected intensity from the sample and metal blocks. This ratio is a function of the direction of the plane of polarization of the beam and also of the angle of incidence of the beam on the sample. The beam from the source was highly polarized but an additional wire grid analyser effectively produced complete polarization. The results of the measurements are shown in figures 8 and 9.

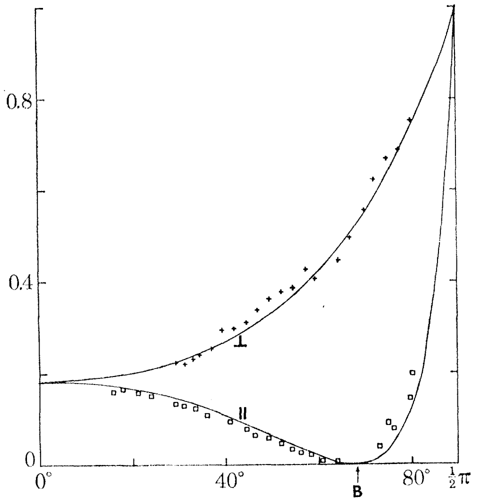

FIGURE 8

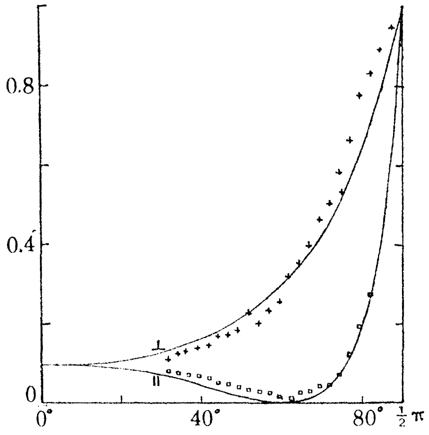

FIGURE 9

FIGURE 8. Reflexion measurements for the block 12063,96. The coefficient of reflexion R_θ is shown as a function of the angle of incidence θ. Plane polarized 338 μm radiation was used, (*a*) when the E vector was in the plane of incidence indicated by squares, (*b*) when the E vector was perpendicular to the plane of incidence indicated by crosses. The continuous curves refer to the corresponding Fresnel expressions for reflexion from a non-absorbing material of dielectric constant 6.25. B indicates Brewster's angle.

FIGURE 9. Reflexion measurements from the block 10065, 30 of breccia. The symbols are used in the same context as in figure 8. The continuous curves are computed for the value of dielectric constant 3.7.

2. DISCUSSION

The direct analysis of the measurements of the far infrared properties of lunar rock has already been described in a number of publications (Bastin *et al.* 1970; Ade *et al.* 1971; Clegg *et al.* 1972; Pugh *et al.* 1972). However, it is here convenient to summarize the scope of applications of the measurements which are of importance in connection with the following problems:

(i) The thermal evolution of the Moon and in particular the outward lunar heat flux. Although this heat flux has now been measured directly it seems likely that during various stages in the thermal evolution of the Moon the heat flux had a temporarily enhanced value, the magnitude of which depends on the effective conductivity of powdered samples. Such models have been shown by Urey *et al.* (1971) to be chemically consistent with the observed properties of lunar rock. The author has shown (Bastin 1974) that such models are physically possible and reproduce with some exactness the topographical conditions found in many types of lunar surface. For this reason it is important to investigate thoroughly the far infrared properties of various types of lunar rock since as has already been pointed out (Bastin *et al.* 1970) there is a strong connection between the infrared absorption properties of lunar rock and the effective thermal conductivity which consists of both radiative and lattice components. The earth-based near infrared measurements of the lunar surface give good agreement with measurements of the conductivity of lunar fines measured in the laboratory (Cremers *et al.* 1971). However, in view of the measurements made by Ade *et al.* (1971) it seems that this agreement may be fortuitous and depend on the effects of close packing in the laboratory measurements and the occurrence of a small fraction of high conductivity rocks lying on the lunar surface.

(ii) The far infrared properties of diffuse dust clouds in space. It is becoming increasingly clear that at some stages in the formation of protostars these objects give out large amounts of millimetre and submillimetre radiation. The comparison of models for such sources with observation require the real and complex refractive indices of dust grains together with a knowledge of their far infrared electromagnetic scattering properties. It seems possible that the lunar regolith fines may be chemically similar to such galactic dust clouds and may have been formed by very similar mechanisms.

(iii) The comparison of observations of measurements on lunar rock with far infrared mapping observations of the Moon. This work has as one of its major objects the establishment of the Moon as a more reliable comparison source for far infrared astronomy.

We wish to thank the Director of E.M.I. Wells and Mr D. Gill and Mr B. Prewer from his staff for use of a cyanogen laser used in connection with the scattering experiments.

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