LETTERS TO THE EDITORS

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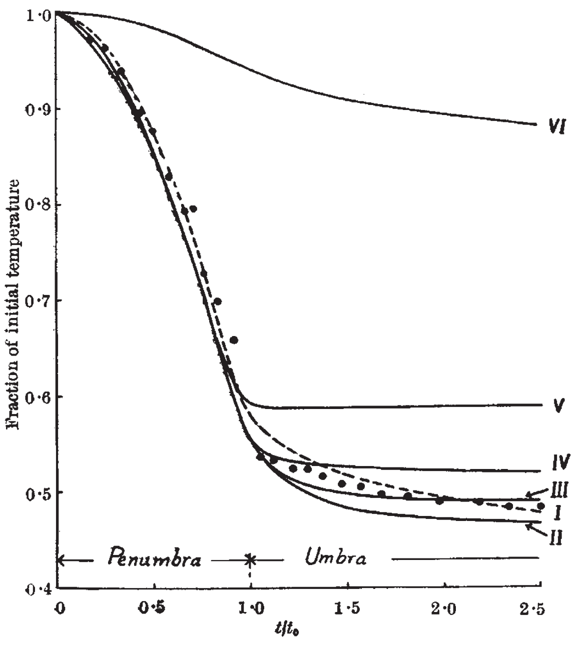
Nature of the Surface of the Moon

THE question of the nature and temperature of the lunar surface has recently acquired a new interest since microwave radar observations of the temperature have become possible. Twenty years ago Pettit, working in the infra-red, measured the fall of surface temperature during a lunar eclipse, and from this information Epstein[1] deduced that most of the surface is covered with a material the thermal properties of which are comparable with those of pumice. If K, ρ and c are the thermal conductivity, density and specific heat of the lunar material (assumed to be constant), t_0 is the duration of penumbra, and A is the insolation before the eclipse, he gave the formula

$$\frac{4At^{3/2}}{3t_0(\pi K\rho c)^{1/2}}, \qquad (1)$$

for the fall of temperature up to time t after the beginning of penumbra, and from the observations deduced $(K\rho c)^{-1/2} = 120$, the units being C.G.S. and ° C. The source of this formula was not stated, but it is, in fact, that for the surface temperature of a semi-infinite solid from which heat is extracted at the rate At/t_0 per unit time per unit area. This is equivalent to assuming that the surface loses heat during the eclipse at a rate proportional to the fourth power of its initial temperature, instead of to the fourth power of its actual temperature, and since the temperature-range involved is from 370° K. to about 200° K., formula (1) will give values which are far too large. To get an accurate result, the non-linear equations must be studied numerically: this has been done recently by Wesselink[2], who finds a value $(K\rho c)^{-1/2} = 920$, and shows that this value is consistent with dust at low pressures (he does not point out the incorrectness of Epstein's calculation, and, indeed, states that their results agree, which by a coincidence they do, though, in fact, they are in different units).



We made similar calculations in connexion with the microwave observations of Piddington and Minnett[3], but have taken the matter a good deal further. In the accompanying graph, the dots show Pettit's[4] observations of the 1939 eclipse, while curve I is calculated for a solid with $(K\rho c)^{-1/2} = 1{,}030$: the main discrepancy between the two is the fact that the experimental curves fall much more slowly than the calculated ones in the umbral phase. This discrepancy is not removed by changing the value of $(K\rho c)^{-1/2}$, which simply moves the later parts of the curves up or down. Two possible explanations may be suggested: (i) that it is an effect of the variation of thermal conductivity with temperature; or (ii) that the solid is not homogeneous. With regard to (i), we can only say that we have not been able to reproduce the experimental curves with likely laws of variation of conductivity with temperature. With regard to (ii), however, it has been shown[3] that the microwave results cannot be explained on the assumption of a homogeneous solid, but that a good fit is obtained by assuming that a thin skin, of conductivity K and thickness d, lies on a substratum with thermal constants K', ρ', c', provided that the quantities are related by

$$d = 610\, K(K'\rho'c')^{-1/2}. \qquad (2)$$

Assuming this surface layer to be dust with $K = 2{\cdot}8 \times 10^{-6}$ (which with the reasonable values $c = 0{\cdot}2$, $\rho = 1{\cdot}7$ corresponds to the $(K\rho c)^{-1/2} = 1{,}030$ of curve I), we have repeated the eclipse calculation for various values of d and $(K'\rho'c')^{1/2}$ satisfying (2). Curves II, III, IV and V of the figure are for the values 0·24, 0·17, 0·12, 0·05 of d with the corresponding values of 140, 100, 70, 30 of $(K'\rho'c')^{-1/2}$. Since curve III gives the best fit, we conclude that the surface behaves like a layer of about 2 mm. of dust on a substratum for which $(K'\rho'c')^{-1/2}$ is about 100. This value corresponds to the terrestrial values for substances such as pumice or gravel and suggests that the surface consists of granular matter interspersed with dust which lies on top of it to a depth of about two millimetres.

Finally, it should be remarked that the observed temperature is an average over a small region of the surface, and that it is possible that portion of the region may be covered with bare rock and the remainder with dust. Curve VI shows the corresponding result for bare rock, $(K\rho c)^{-1/2} = 20$, and by combining this with the others it appears that it is unlikely that more than 5 per cent of the surface is bare rock.

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[1] Epstein, P., *Phys. Rev.*, **33**, 269 (1929).
[2] Wesselink, A. J., *Bull. Astro. Inst. Netherlands*, **10**, 351 (1948).
[3] Piddington, J. H., and Minnett, H. C., *Aust. J. Sci. Res.*, **2**, 63 (1949).
[4] Pettit, E., *Astrophys. J.*, **91**, 408 (1940).

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