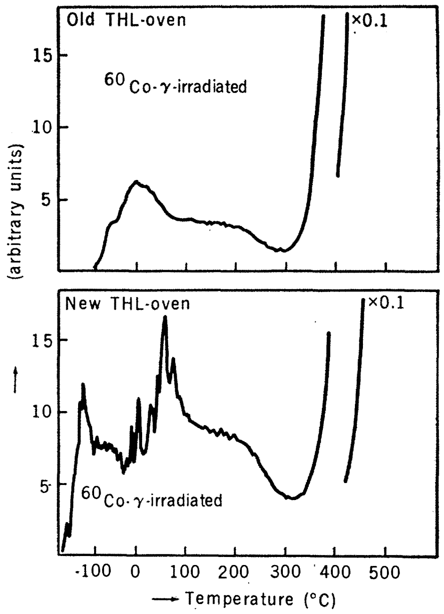

Fig. 2. Thermoluminescence glow curves of lunar dust (sample 10084); (upper curve) 40-mg sample; irradiated for 15 minutes; heating rate, 100°C/min; (lower curve) 47-mg sample; irradiated for 15 minutes; heating rate, 100°C/min.

several meters) should be measurable.

During the last decade the natural β^- activity of ^{187}Re was used by us successfully for geological age determinations (*8*). We showed that the ^{187}Os abundance varies considerably in the Re-containing minerals and in iron meteorites. It was pointed out, and D.D. Clayton showed this later in a detailed study, that the larger part of the terrestrial (stable) ^{187}Os should be regarded as having resulted from ^{187}Re decay and that most of that decay occurred before the formation of the solar system. These ideas are based on the now accepted s-process theory.

The β^- energy of ^{187}Re is extremely weak (~2 keV) and a problem arises about the mode of this decay. Quite recently Clayton (*9*) outlined the possibility that the radioactivity of ^{187}Re could be dependent on temperature and isotopic measurements of Re from lunar dust ("solar wind") could clarify the interesting problem of ^{187}Re cosmochronology. In view of these cosmological questions, we found it necessary to establish the presence of Re in lunar dust. As the abundance in Fe-meteorites is normally below 1 ppm, only neutron activation with chemistry could succeed. "Fines" (176 mg) were irradiated together with Re standards for 3 days, $\phi = 7 \times 10^{13}$ in the FRJ-2 reactor. Thereafter the mineral was fused by melting with NaOH + Na_2O_2 in the presence of 30 mg of Re-carrier. Several $Fe(OH)_3$ precipitations were followed by repeated dry distillation of Re_2O_7. The decay of ^{186}Re is observed. The Re content of soil (sample 10084, grains <100 μ) is calculated to be 11.2 ± 0.4 ppb if one assumes a normal terrestrial isotope abundance.

In the next step it is important to check the isotope ratio ^{187}Re/^{185}Re.

The thermodifferential analysis (TDA) and thermogravimetric analysis (TGA) curves (Fig. 1) show distinct temperature regions where gas-loss and recrystallization or annealing occurs. A critical temperature is seen at about 510°C. Oxidation at 800°C leads to a gain in weight of about 2 percent (see the lower TGA curve).

By mass spectroscopy, ratios of ^{3}He/^{4}He = 724 ± 118, ^{20}Ne/^{22}Ne = 2.34 ± 0.04, and ^{22}Ne/^{21}Ne = 22.6 ± 6 were measured in dust. Only the ^{20}Ne/^{22}Ne ratio is found to be very constant.

Nuclear γ-resonance spectroscopy (with ^{57}Fe) was done on magnetic and nonmagnetic fractions of lunar fines. No trace of Fe^{3+} was detected. Troilite was practically not observed in the soil but metallic Fe, ilmenite, pyroxene, and olivine were present. The spectra were compared with those of tektites and the existence of an unknown Fe^{2+}-containing compound in the lunar soil is proposed (see Table 2).

For the thermoluminescence study different soil fractions were used. However, after 8 weeks of "storing" time we did not detect any natural THL with certainty. Probably the skin layer of dust is already strongly annealed on the moon. Highest glow intensities occur in the temperature range of 100° to 150°C, if irradiated at 30°C. At −196°C γ-irradiation the intensity is considerably greater. A ^{60}Co-γ-saturation experiment shows that saturation for the soil is reached at a dose of about 10^6 rads (see Fig. 2).

These preliminary results demand better defined and selected material probes.

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Specific Heats of Lunar Surface Materials from 90 to 350 Degrees Kelvin

Abstract. *The specific heats of lunar samples 10057 and 10084 returned by the Apollo 11 mission have been measured between 90 and 350 degrees Kelvin by use of an adiabatic calorimeter. The samples are representative of type A vesicular basalt-like rocks and of finely divided lunar soil. The specific heat of these materials changes smoothly from about 0.06 calorie per gram per degree at 90 degrees Kelvin to about 0.2 calorie per gram per degree at 350 degrees Kelvin. The thermal parameter* $\gamma = (k\rho C)^{-1/2}$ *for the lunar surface will accordingly vary by a factor of about 2 between lunar noon and midnight.*

The surface temperature of the moon varies from approximately 90° to 385°K between lunar noon and midnight (*1, 2*).

Cooling of the lunar surface depends on the so-called thermal parameter, $\gamma = (k\rho C)^{-1/2}$, where k is the thermal conductivity, ρ is the density, and C is the specific heat. Most calculations of lunar surface temperature that use earth-based eclipse data (*1, 3*) have assumed a constant value of γ. However, specific heats of silicates vary by a factor of 3 or 4 in the temperature range 100° to 400°K. Accordingly, γ should show a nearly twofold variation over the range of lunar surface temperatures.

In order to verify the temperature dependence of γ, we have determined the specific heats at approximately 8°K intervals between 90° and 350°K for the samples 10057 and 10084 from Apollo 11.

The low-temperature adiabatic cal-

Table 1. Specific heats in cal g^{-1} deg^{-1} (smoothed values) for lunar samples 10057 (vesicular basalt) and 10084 (regolith). Values in parentheses are extrapolated.

Temperature (°K)	Sample 10057	Sample 10084
90	(0.0571)	(0.0615)
100	.0633	.0665
120	.0771	.0802
140	.0922	.0955
160	.1075	.1108
180	.1217	.1235
200	.1343	.1348
220	.1451	.1446
240	.1546	.1534
260	.1632	.1617
280	.1711	.1696
300	.1786	.1771
320	.1853	.1845
340	.1917	.1916
360	$(.198_3)$	$(.197_0)$

orimeter used in this investigation and details of the measurement technique and data reduction are discussed in detail by Robie and Hemingway (*4*).

Special sample holders were built for the lunar sample measurements from aluminum rod (T 6061 alloy). They are 5.1 cm deep with a 3.2-cm inside diameter, and they have a central reentrant well of 0.48-cm internal diameter with a length of 3.8 cm. The containing walls are 0.05 cm thick. The surface has a 10-microinch (mirror) finish. The sample holder has a mass, including the top, of 20.5 g and an internal volume of 42.2 cm^3.

A miniature platinum resistance thermometer (Minco 1059) with an ice point resistance of 100.09 ohms and sensitivity of 0.4 ohm deg^{-1} was used to determine the absolute temperatures (*5*). It is inserted within an aluminum bobbin externally wound with a 53-ohm "Evanohm" heater attached with Glyptal (G.E. 7031) and is brought into good thermal contact with the sample container using Apiezon T stopcock grease. The bobbin with the thermometer in place slip-fits within the reentrant well of the sample holder body and is brought into thermal contact using Apiezon T stopcock grease.

Table 2. Thermal constant γ (in cm^2 $sec^{1/2}$ °K cal^{-1} for lunar samples 10057 and 10084. Values for sample 10057 were obtained by using $k = 0.004$ cal cm^{-1} deg^{-1} sec^{-1} and $\rho = 3.4$ g cm^{-3}. Values for sample 10084 were obtained by using $k = 0.000004$ cal cm^{-1} deg^{-1} sec^{-1} and $\rho = 1.6$ cm^{-3}.

Temperature (°K)	Sample 10057	Sample 10084
100	34.33	1543
150	27.12	1231
200	23.40	1078
250	21.51	1000
300	20.29	941
350	19.41	898

To preserve the samples in as nearly their pristine state as possible the samples were loaded into the aluminum containers at the Lunar Receiving Laboratory and sealed under dry nitrogen gas at 5 psi. The heat capacity of the empty sample containers was determined in a separate set of experiments. The raw data (electrical energy/ ΔT) were corrected for small deviations from true adiabatic conditions (that is, zero heat exchange between sample container and its surroundings) and for the heat capacities of the aluminum sample holder, N_2 exchange gas, and Teflon tape seal. The use of aluminum for the sample containers instead of copper, and of dry nitrogen instead of helium gas, reduces the precision of specific heat measurements by increasing the time constant of the calorimeter. The empty calorimeter contributed about 50 percent to the total observed heat capacity at 90°K and about 30 percent of the total at 350°.

The experimental data for sample 10057 are shown in Fig. 1. The results for the regolith sample, 10084, are similar. The temperature rise for each point was between 3.7° and 10.2°K. The accuracy of the data is ±0.4 percent. The corrected specific heats were smoothed using a form of least-squares orthogonal polynomials. The smoothed specific heat values are listed, at 20°K intervals, in Table 1.

If we neglect the small temperature variation of the thermal conductivity, we can calculate the temperature dependence of γ from the specific heats listed in Table 1, the measured densities (*6*), and reasonable estimates for the thermal conductivities. Scott (*7*) lists values for the thermal conductivity of evacuated, porous, silica-based materials of between 2.4 and 5.2 μcal cm^{-1} deg^{-1} sec^{-1}. These should be comparable to the conductivity of the lunar regolith. Using a bulk density of 1.6 g cm^{-3} as determined from the Apollo 11 core tube samples (*6*) and a mean conductivity of 4.0 μcal deg^{-1} cm^{-1} sec^{-1}, we obtain for the thermal parameter γ of the lunar soil (sample 10084), values of 1600 cm^2 $sec^{1/2}$ °K cal^{-1} at 90°K and 898 cm^2 $sec^{1/2}$ °K at 350°K.

In contrast, a large lunar outcrop of type A rock that has a conductivity of the order of 0.004 cal cm^{-1} deg^{-1}

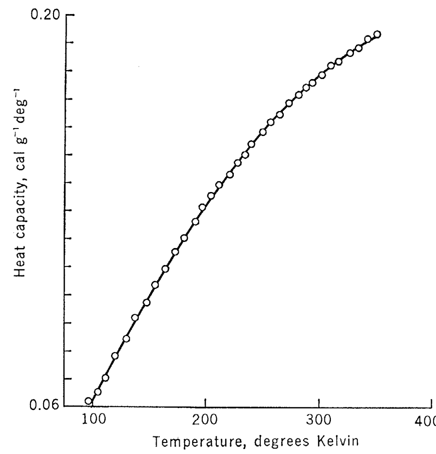

Fig. 1. Specific heat of Apollo 11 sample 10057. Circles indicate experimental observations. The full line is the least-squares fit to the data.

sec^{-1} would have a γ at 90°K of 35.9 cm^2 $sec^{1/2}$ °K cal^{-1}, which would decrease to 19.4 cm^2 $sec^{1/2}$ °K cal^{-1} at 350°K. In this calculation we have used Robertson's data (*8*) for the conductivity of vesicular basalt. The difference in the thermal parameter of the lunar soil and lunar outcrop values is due to the very large difference in the thermal conductivities between the porous soil (in a high vacuum) and the solid rock. Inasmuch as γ depends on the rate of cooling, the dust-covered portions of the lunar surface will cool much more rapidly than bare exposed outcrop, and thermal anomalies (*2*) will quickly develop over the exposed solid rock.

In Table 2, we list values for γ at several temperatures between 100° and 350°K for the lunar soil (10084) and for the vesicular basalt (10057).

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