# ELECTRICAL CONDUCTIVITY OF OLIVINE AND THE LUNAR TEMPERATURE PROFILE

R. M. HOUSLEY and F. J. MORIN

*North American Rockwell Science Center, Thousand Oaks, Calif., U.S.A.*

**Abstract.** The measured electrical conductivity of olivine has been shown to depend strongly on the $P_{O_2}$ in which the sample has been equilibrated. At the present time, no definite limits can be placed on temperatures in the lunar interior assuming a model composition of olivine. It is certain that such limits will be at least several hundred degrees above the original estimates.

The response of the Moon to changes in the surrounding magnetic field may be determined by comparing the readings of magnetometers on the lunar surface with that of the magnetometer orbiting the Moon in Explorer 35 (Sonett *et al.*, 1971; Dyal and Parkin, 1971). The analysis of data so far available in terms of induced electrical currents in the lunar interior provides considerable information on the electrical conductivity versus radius profile of the Moon, and further refinements of this profile can be expected as data accumulate and analytical methods are improved.

The electrical conductivity profile in principle provides an important constraint on models of the composition and thermal history of the lunar interior. In order to utilize this constraint in a reasonable way, however, it is necessary to know the electrical conductivity versus temperature of proposed lunar interior materials *in equilibrium* under the conditions of pressure and *chemical environment*, which are considered possible for the lunar interior.

It has been suggested (Sonett *et al.*, 1971; Dyal and Parkin, 1971) that an upper limit for the lunar temperature profile could be obtained from the electrical conductivity profile by assuming forsteritic olivine as a model composition since it is the least conducting terrestrial rock type for which data is available. We will show that available data on olivine in fact do not allow a meaningful limit to be placed on the lunar temperature profile.

Although a number of studies of the electrical conductivity of olivine, in a range of compositions, versus temperature (Jander and Stamm, 1932; Coster, 1948; Noritomi, 1961; Mizutani and Kanamori, 1967; Kobayashi and Maruyama, 1971) and in some cases pressure (Hughes, 1955; Parkhomenko and Bondarenko, 1962; Bradley *et al.*, 1964; Akimoto and Fujisawa, 1965; Hamilton, 1965) have been reported, there has been no systematic study of the effect of equilibrating the samples in different chemical environments. Since one of the outstanding characteristics of lunar surface rocks is the presence of free Fe metal and the absence of significant $Fe^{3+}$, implying crystallization under conditions of very low $P_{O_2}$, it seemed to us essential to check the effect equilibration in atmospheres of different $P_{O_2}$ on the electrical conductivity of olivine.

For our initial exploration of the effects of $P_{O_2}$, we constructed a simple apparatus in which a sample having approximate dimensions $2 \times 2 \times 10$ mm was held between two ceramic rods extending to a cylindrical metal box at room temperature at one

Communication presented at the Conference on Lunar Geophysics, held between October 18–21, 1971, at the Lunar Science Institute in Houston, Texas, U.S.A.

end of the furnace. The tube furnace was capable of maintaining temperatures up to 1100 °C. The ceramic furnace tube was electrically shielded with platinum in electrical contact with the sample support box. Gases were mixed in a simple manifold arrangement. Contacts were put on the samples by decomposing chloroplatinic acid in air at about 500 °C for a short time. Resistance was measured with a Keithley model 610B

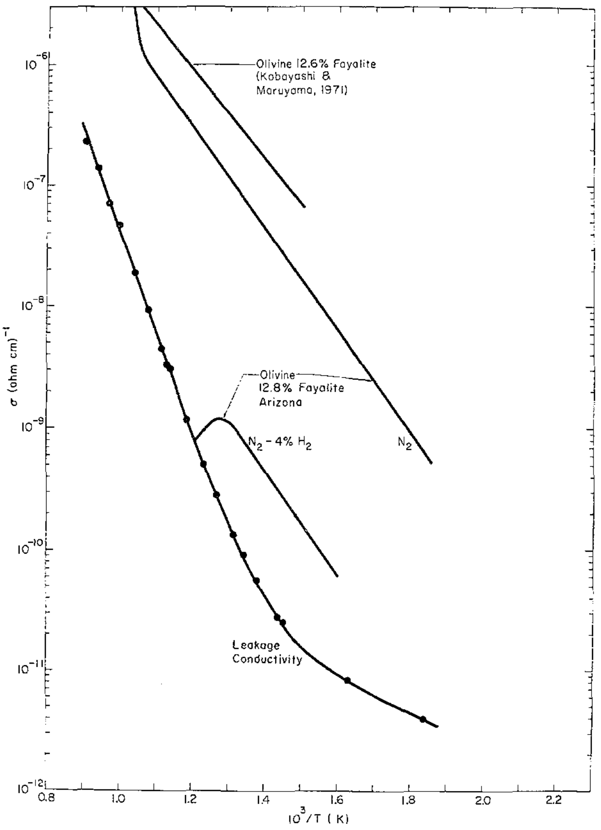


Fig. 1. Experimental electrical conductivity data on olivine. Lower curve is the apparent conductivity which would be inferred, for samples of the size and shape used, from the largely thermionic leakage currents measured with no sample in the holder. The top curve shows recent data of Kobayashi and Maruyama (1971) on a sample with fayalite content similar to ours. The other two curves show results on two of our samples heated in different atmospheres as indicated.

electrometer. Samples were cut from nearly flawless olivine crystals containing about 12% fayalite from Arizona.

In our first run, the contacts were fired for several minutes and the atmosphere used during the measurements was commercial purity $N_2$. The resulting conductivity data when plotted versus $1/T$ gave a straight line similar in position to those obtained by Kobayashi and Maruyama (1971) with a corresponding activation energy of 0.8 eV, for measurement temperatures up to 700 °C. Above this temperature, the conductivity rapidly increased at constant temperature. These results are shown in Figure 1 where the exact shape in the curving parts of the lines was determined largely by the time interval between measurements.

In three subsequent runs on two additional samples, the contacts were only fired in air for one minute initially. These runs were all done in $N_2-4\%H_2$. The resistance of these samples at low temperature was about two orders of magnitude higher than that of sample one and at about 600 °C it increased at constant temperature and in less than 12 hr reached a value which we could no longer distinguish from our thermionic leakage currents as can be seen in Figure 1. In our first run under these conditions, the sample was heated only a little above 600 °C. Upon cooling the furnace, we examined the sample and found the contacts to be in perfect condition and the sample itself to have changed color only very slightly. In none of these runs did we observe fluctuating readings which are the experimental indication of bad electrical contacts.

These results show the strong influence of $P_{O_2}$ on the measured electrical properties of olivine and certainly show that available data cannot be used to obtain an upper limit for temperatures in the lunar interior. If the limiting conductivity of olivine under conditions of low $P_{O_2}$ were as large as can be allowed by our present data, the previous estimated limits (Sonett *et al.*, 1971; Dyal and Parkin, 1971) would have to be increased at least 200–300 °C.

The strong effect of the procedure for putting electrical contacts on our samples on the initial electrical conductivity suggests that surface conduction may be contributing to the measured results. None of the previous investigators have employed techniques which would distinguish surface from bulk conductivity.

We are currently completing an apparatus of the type described by Özkan and Moulson (1970) which will eliminate interference from both thermionic and surface currents. With that we intend to obtain quantitative data on the effect of $P_{O_2}$ and other factors on the electrical conductivity of olivine as part of a program devoted to studying conduction mechanisms in insulators of geophysical interest.

**Acknowledgements**

The able assistance of Pete Crandall in preparing the samples and of Dennis Hengstenberg in determining the fayalite content is greatfully acknowledged.

**Note added in proof.** Since writing the enclosed manuscript, we have made some runs with the new apparatus and can conclude: (1) The true conductivity of olivine is several orders of magnitude lower than the results previously set by our leakage currents. (2) Surfacc conduction was indeed a serious problem in our other apparatus. (3) AC and DC measurements lead to the same results.

## References

Akimoti, S. and Fujisawa, S.: 1965, *J. Geophys. Res.* **70**, 443–449.
Bradley, R. S., Jamil, A. K., and Monro, D. C.: 1964, *Geochim. Cosmochim. Acta* **28**, 1669–1676.
Coster, H. P.: 1948, *Monthly Notices Roy. Astron. Soc., Geophys. Suppl.* **5**, 193–199.
Dyal, P. and Parkin, C. W.: 1971, *J. Geophys. Res.* **76**, 5947–5969.
Hamilton, R. M.: 1965, *J. Geophys. Res.* **70**, 5679–5692.
Hughes, H.: 1955, *J. Geophys. Res.* **60**, 187–191.
Jander, W. and Stamm, W.: 1932, *Z. Anorg. Allgem. Chem.* **207**, 289–307.
Kobayashi, Y. and Maruyama, H.: 1971, *Earth Sci. Letters* **11**, 415–419.
Mizutani, H. and Kanamori, H.: 1967, *J. Phys. Earth* **15**, 25–31.
Noritomi, K.: 1961, *J. Mining College, Akita Univ.*, Ser. A **7**, 27.
Özkan, O. T. and Moulson, A. J.: 1970, *J. Phys. D* **3**, 983–987.
Parkhomenko, E. I. and Bondarenko, A. T.: 1962, *Trans. Inst. Phys. Earth Acad. Sci. U.S.S.R.* (Tr. Inst. Fiz. Zemli, Akad. Nauk *S.S.S.R.*), **23**, 101–106.
Sonett, C. P., Colburn, D. S., Dyal, P., Parkin, C. W., Smith, B. F., Schubert, G., and Schwartz, K.: 1971: *Nature* **230**, 359–362.