

TABLE 1. Sample Description

Sample	Locality	Source	Composition
12	Mt. Leura, Camperdown, Victoria, Australia	Mineral collection, Dep. of Geophys. Sci., Univ. of Chicago	Fa 7.7
18	San Carlos Indian Reserv., Ariz.	E. J. Olsen, Field Mus. of Natural Hist., Chicago	Fa 8.2
35	St. John's Island, Red Sea, Egypt	Mineral collection, Dep. of Geophys. Sci., Univ. of Chicago	Fa 9.4
36	Crater Elegante, Sierra Del Pinacote volcanic field, Sonora, Mex.	D. Johnson, Geol. Dep., Stanford Univ., Palo Alto, Calif.	Fa 26.4
38	Synthetic forsterite (grown by Linde flame-fusion process)	O. L. Anderson, Lamont-Doherty Geol. Observ., Columbia Univ., Palisades, N. Y.	Fa 0 (wt %: SiO ₂ , 43.02; MgO, 56.82; MnO, 0.16; others, <0.01*)

*From *Kumazawa and Anderson* [1969].

below 700° and 500°C, respectively, but in all other instances effects of leakage conductance vanished above about 200°C.

Since the temperature gradient may be quite large in this simple furnace, accurate temperature measurement at the sample was necessary. This accuracy was accomplished by having the chromel-alumel thermocouple contact the sample and serve as one electrode. A new thermocouple was used for each sample; these thermocouples were calibrated at the NaCl melting point, and the reported temperatures are believed to be correct to within 2°–3°. Temperature readings were corrected for the effect of pressure on chromel-alumel thermocouples [Getting and Kennedy, 1971].

Carbon from trace amounts of hydrocarbons in the argon and 'O'-ring 'dust' from intensifier packings were major problems in these experiments. Many experiments were terminated at about 500°C when a thin carbon film was deposited in the sample region and the measurement was shorted out. Secondary heaters, both with and without titanium-zirconium alloy getters, were ineffective, as was running the primary heater at elevated temperatures and allowing the carbon to deposit in the cooler regions of the furnace away from the crystal, as was suggested by *Hughes* [1955]. The method that effectively removed the carbon was the introduction of a small amount of oxygen (less than 0.03%) into the argon to

oxidize the hydrocarbon in a secondary furnace located in the pressure vessel away from the sample.

The introduction of oxygen into an atmosphere in which one is measuring the σ of a semiconductor such as olivine will affect the conductivity [Shankland, 1969; Plusckell and Engell, 1968; Hamilton, 1965]. Irreversible σ changes in the samples were checked experimentally by continuously cycling back to lower temperatures after every 100°–200°C increase in temperature and repeating measurements. In this way one could easily detect chemical change due to oxidation of the olivine (or to the appearance of carbon), because irreversible increase in conductance ensued in either case. Carbon began to appear above 500°C, and oxidation was noted to begin at about 800°C, both temperatures being somewhat dependent on oxygen content.

Confining pressures were generated in standard separators and intensifiers, in which argon was the pressure medium. Pressure was measured by the resistance change of a manganin coil that had been calibrated against a 7-kb Heise pressure gage with an accuracy of 0.1%. The accuracy of the pressure measurement is better than 0.5%, and precision is 0.1%.

Conductance was measured at 1000 Hz and 30 volts with a General Radio 1615-A capacitance bridge with a stated accuracy of 1%. The σ measured was assumed to be independent of

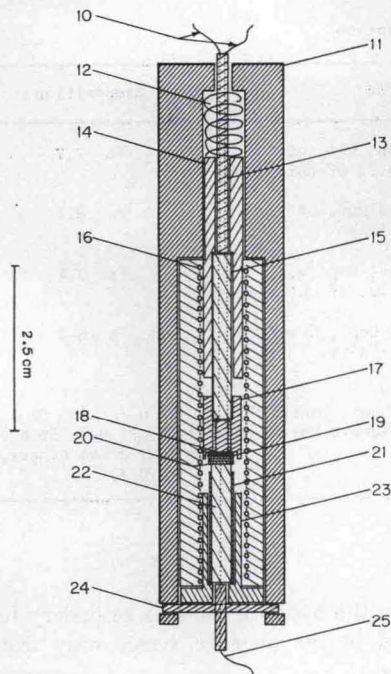


Fig. 1. Sample holder. Numbers on the diagram are as follows: 10, thermocouple leads; 11, lavite cylinder; 12, steel spring; 13, alumina tubing; 14, bottom lavite cap; 15, alumina tubing; 16, primary furnace; 17, alumina crystal holder; 18, chromel-alumel thermocouple; 19, olivine crystal; 20, platinum electrode; 21, 0.001-inch tungsten foil; 22, alumina tubing; 23, top lavite cap; 24, nickel rod; and 25, platinum wire to electrode.

frequency, as was indicated by the results of *Hamilton* [1965] and *Bradley et al.* [1964] for powders. Conductances of 10^{-8} mho and greater were measured with a circuit similar to that used by *Schock* [1966]. The σ is calculated from the measured conductance

$$\sigma = G(t/A) \quad (2)$$

where t is the thickness and A is area of the sample.

EXPERIMENTAL PROCEDURE

In a typical run the oxygen was introduced into the first-stage argon compressor to yield a mix of argon to oxygen of 3.6×10^3 . The system was then pressurized to 7.5 kb, and the secondary furnace was heated to about 1000°C for 1 hour before σ measurements were begun. Measurements were made as a function of temperature at constant pressure; temperature

cycles were reversed every 100–200°C to verify reproducibility and to check for anomalous behavior due to the presence of excess carbon or oxygen. After achieving a temperature of 750°C at 7.5 kb, the temperature was lowered to around 100°C, the pressure was lowered to 5.00 kb, and the procedure was repeated. For all compositions except the Fa 7.7 olivine runs were made at 7.50, 5.00, and 2.50 kb. Runs at 7.50 kb were made with at least two different samples for each crystal direction to determine the variation of σ with direction for the Fa 8.2. Reproducible data at temperatures greater than 1000°C were achieved only for the Fa 0 and the Fa 9.4. The chief limiting factor for the runs made at higher temperature was oxidation of the crystal or the thermocouple or both.

DATA AND ANALYSIS

Figure 2 illustrates the σ of olivine as a function of temperature, pressure, and composition for all samples studied. Lines are plotted from a linear-regression analysis of the σ data. Equations of the lines shown in Figure 2, along with standard deviations, can be found in Table 3. Because the pressure variation of the Fa 8.2 is so small, it is not plotted in Figure 2.

With the exception of the Fa 9.4, the σ has a tendency to increase with fayalite content. The Fa 26.4 and the Fa 9.4 single crystals do not fit the behavior of powders in which activation energy decreases with iron content [*Bradley et al.*, 1964], although the other three compositions do follow this behavior.

The difference in activation energies for σ in olivines with almost the same iron content is puzzling and might seem to be due to impuri-

TABLE 2. Leakage Conductance

Temperature, °C	Leakage Conductance, 10^{-12} mho	Olivine Conductance,* 10^{-12} mho
24	1.0×10^0	1.8×10^2
100	4.0×10^1	5.1×10^2
200	7.3×10^1	1.6×10^3
300	8.9×10^1	2.2×10^4
400	9.8×10^1	1.8×10^5
500	1.0×10^2	1.9×10^6
600	2.2×10^2	5.2×10^6
700	3.9×10^2	7.7×10^6
800	4.4×10^2	1.8×10^7
900	1.7×10^3	6.1×10^7
1000	4.0×10^3	1.8×10^6
1100	1.0×10^4	3.2×10^6
1200	3.2×10^4	1.2×10^7

*Measurements above 900°C made on Fa 9.4; measurements below 900°C made on Fa 8.2.