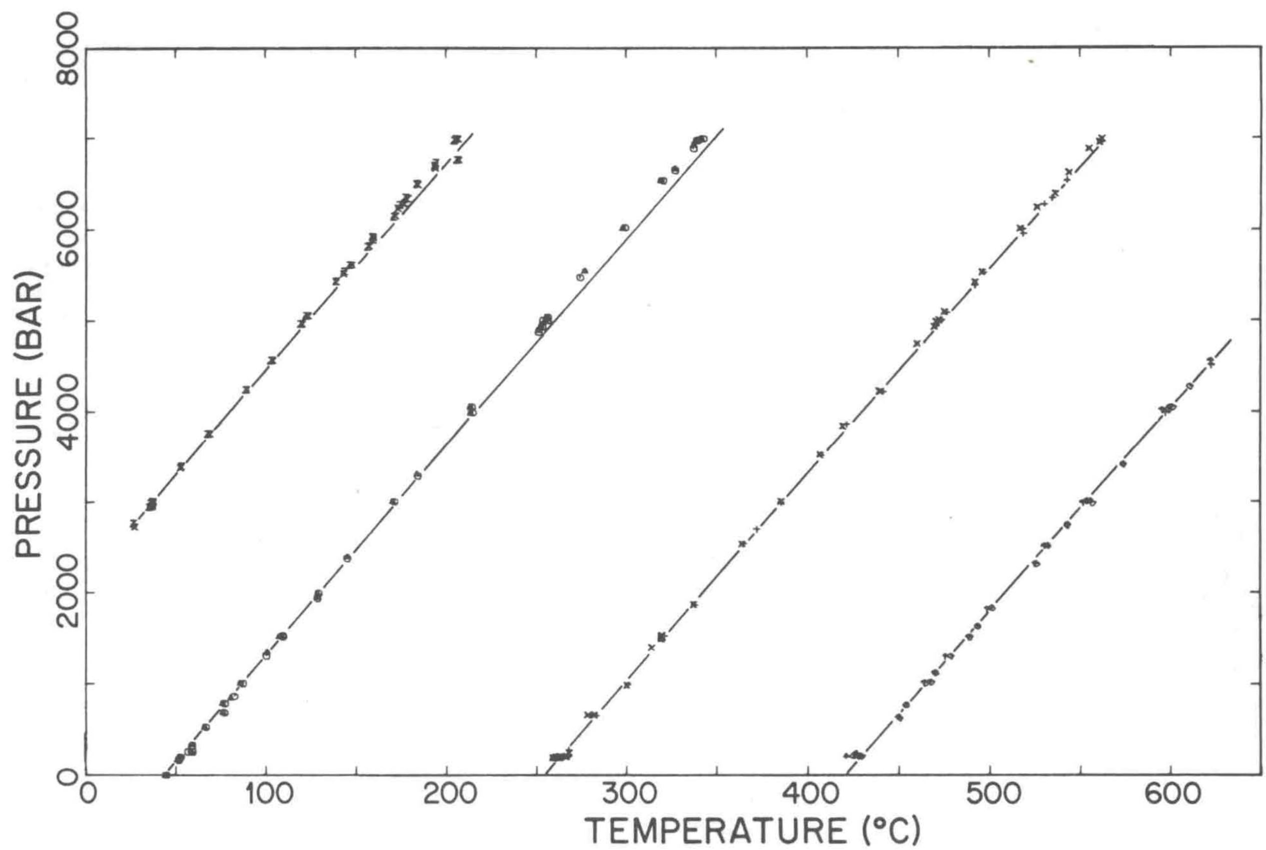

FIG. 9. Data obtained with "gate" dilatometer (WC gate) for four isomekes between synthetic periclase and synthetic halite. Solid lines are isomekes calculated from results of ultrasonic measurements by Spetzler (1969) and Spetzler *et al* (1972).

and it will be interesting to obtain an independent value for it. The success in determining β_s and the independent replication of α_s using two different isomekes suggests that the "gate" dilatometer provides accuracy that is, perhaps, sufficient for study of equations of state of solids. This is a task whose demands for experimental accuracy considerably exceed those of solid inclusion piezothermometry.

Critique. The most important reasons for adoption of the "gate" over the "J" and "opposed rods" devices are: (1) The difficult machining is concentrated into one base that is used for all experiments. Only the rods of minerals to be compared need separate machining, a task easily accomplished with conventional equipment. (2) It is unnecessary to coat the mineral rods to form an electrical circuit. (3) All of *P-T* space is accessible to isomeke determinations with only one experimental assembly, merely by appropriate adjustment of the gap between one or the other ball contacts and gate. (4) The mineral rods used are much less demanding of large single crystals. (5) The gate device, with sensitivity to strain differences $\approx 10^{-6}$, appears to be more precise by about an order of magnitude. (6) The symmetrical design and better thermocouple placement probably improve accuracy. (7) Because of the hinged gate, there is no resetting by sliding of rods on the fiducial ridges if care is taken in adusting forces of the spring clamps relative to that of the gate spring. (8) The guiding channels for electrical leads in the base and the supports S and clamps C greatly reduce the likelihood of short circuits due to movement of components. (9) The gap that determines location of an isomeke can, with practice, be more precisely set because of doubling of the *apparent* gap due to reflection by the polished gate. (10) Once assembly is completed, the gate device permits convenient and rapid switching of rods.

Some disadvantages of the "gate" device are: (1) The many more components than those of the other devices require considerable time, care, effort, and complicated procedure for their manufacture. This is especially true of the spinel base. (2) *Initial* assembly of the "gate" device takes considerably longer than assembly of the other devices and requires patience, care, and steadiness of hand. (3) There is a possibility that the balls E will rotate during an experiment and therefore travel slightly across the ends of the rods as a result of differential strain of the wires U and the rods. This is an uncontrolled variable and conceivably could cause a slight experimental inaccuracy. (4) The small longitudinal compressive stresses on the rods, resulting from forces of springs U and Y, are approximately equivalent on both rods and probably have negligible effect.

One minor source of inaccuracy is common to both kinds of dilatometer—the finite width ($\sim$1% of rod length) of the fiducial ridge. It is conceivable that, within the width of the ridge, the "pinning" position of a rod may vary reversibly or irreversibly during the course of an experiment.

If the more demanding needs of determination of equations of state are to be satisfied, it should be possible to modify the "gate" dilatometer to eliminate some of the deficiencies cited. Work is in progress on some of these improvements.

High Pressure Apparatus

Experiments were performed in the internally heated argon high pressure apparatus described by Goldsmith and Heard (1961). Pressure was determined using a 7 kbar Heise Bourdon tube gauge, and temperature was determined with chromel-alumel thermocouples. Electrical and thermocouple leads pass through an axial hole in the closure piston (Goldsmith and Heard, Fig. 1), to two chromel and one alumel thermocouple leads, introduced in the same manner as described by Goldsmith and Heard (1961). Signal power was supplied from a 1-½ volt battery through a resistor across the input of a potentiometric millivolt recorder. Closing the circuit allowed a $\sim 1.4\ \mu A$ current to flow, the presence or absence of which was recorded on the strip chart simultaneously with the thermocouple millivoltage (Figs. 3, 8). Pressure is noted with a precision of better than $\pm$ 5 bar on the strip chart from visual readings of the Heise gauge.

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References

ADAMS, H. G. (1971) *Solid Inclusion Piezothermometry: Experimental Calibration of Quartz-Almandine and Sillimanite-Almandine.* Ph.D. Dissertation, University of California, Los Angeles, 156 p.

———, L. H. COHEN, AND J. L. ROSENFELD (1970) Solid inclusion piezothermometry: Experimental calibration of quartz-almandine and sillimanite-almandine. *Geol. Soc. Am. Abstr. Programs,* **2,** 479.

———, ———, AND ——— (1975) Solid inclusion piezothermometry. II: Geometric basis, calibration for the association quartz-garnet, and application to some pelitic schists. *Am. Mineral.* **60,** 584–598.

BEVINGTON, P. R. (1969) *Data Reduction and Error Analysis for the Physical Sciences.* McGraw-Hill, Inc., New York. 336 p.

BRIDGMAN, P. W. (1949) Linear compressions to 30,000 kg/cm^2. *Proc. Am. Acad. Arts Sci.* **77,** 189–234.

COHEN, L. H., J. L. ROSENFELD, AND H. G. ADAMS (1972) Calibration of the quartz-garnet piezothermometer. *Trans. Am. Geophys. Union,* **53,** 1128.

GOLDSMITH, J. R., AND H. C. HEARD (1961) Subsolidus phase relations in the system $CaCO_3$–$MgCO_3$. *J. Geol.* **69,** 45–74.

HARRIS, J. W., H. J. MILLEDGE, T. H. K. BARRON, AND R. W. MUNN (1970) Thermal expansion of garnets included in diamond. *J. Geophys. Res.* **75,** 5775–5792.

MCSKIMIN, H. J., P. ANDREATCH, JR., AND R. N. THURSTON (1965) Elastic moduli of quartz *versus* hydrostatic pressure at 25° and −195.8°C. *J. Appl. Phys.* **36,** 1624–1632.

ROSENFELD, J. L. (1969) Stress effects around quartz inclusions in almandine and the piezothermometry of coexisting aluminum silicates. *Am. J. Sci.* **267,** 317–351.

———, AND A. B. CHASE (1961) Pressure and temperature of crystallization from elastic effects around solid inclusions in minerals. *Am. J. Sci.* **259,** 519–541.

SPETZLER, H. A. W. (1969) *The Effect of Temperature and Partial Melting on Velocity and Attenuation in a Simple Binary System, Part I. Effect of Temperature and Pressure on Elastic Properties of Polycrystalline and Single Crystal MgO.* Ph.D. Dissertation, California Institute of Technology, Pasadena.

———, C. G. SAMMIS, AND R. J. O'CONNELL (1972) Equation of state of NaCl: Ultrasonic measurements to 8 kbar and 800°C and static lattice theory. *J. Phys. Chem. Solids,* **33,** 1727–1750.

WILSON, E. B., JR. (1952) *An Introduction to Scientific Research.* New York, McGraw-Hill, 375 p.

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