DUFF RE57 0053

Reprinted from THE PHYSICAL REVIEW, Vol. 108, No. 5, 1207–1212, December 1, 1957
Printed in U. S. A.

Investigation of a Shock-Induced Transition in Bismuth*

RUSSELL E. DUFF AND F. STANLEY MINSHALL
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico
(Received August 1, 1957)

The structure of the shock-wave system to be expected in a material which can undergo a polymorphic transition is discussed. It is shown that the slope of the coexistence line in the p-T plane for the transition can be determined from shock-wave measurements at a given initial temperature. Shock waves produced by high explosives were used to investigate the equation of state of bismuth. An electrical contact technique was used to measure shock and free-surface velocities. The transition near 25 kilobars reported by Bridgman was observed but the transition pressure was about 3.5 kilobars higher than in static experiments. Other results indicated that recrystallization is a faster process than melting under shock conditions. Evidence suggests that the relaxation time for recrystallization in bismuth at 42°C and 27 kilobars is less than 1 μsec.

INTRODUCTION

In recent years shock-wave measurements have been used by several investigators[1–6] to determine very-high-pressure equation-of-state data for many liquid and solid materials. In the course of one of these investigations a phenomenon believed to be a polymorphic transition was observed in iron at a pressure of 0.13 megabar.[7] Bridgman[8] tried unsuccessfully to observe this transition statically by measuring the electrical resistivity of similar material. In addition, further shock-wave measurements were not in agreement with theoretical predictions based on the assumptions that the transition observed was a first-order transition in the thermodynamic sense and that the pressure behind the shock wave was uniform in all directions.

In view of these results, shock-wave techniques have been used to make a careful investigation of the transition observed by Bridgman at 25 kilobars in bismuth. This investigation will help establish the validity of dynamic equation-of-state work and shed light on the applicability of the assumptions made in reducing shock-wave measurements to equation-of-state data. Also a lower limit to the rate of transformation of bismuth from one crystal form to another can be gained from these measurements.

THEORY

Walsh[1] has recently prepared an extensive review of the theory, experimental methods, and results of equation-of-state determinations by shock-wave techniques. It is unnecessary to repeat the basic ideas here. It is appropriate, however, to discuss briefly the structure of the shock-wave system which results from a polymorphic transition in a metal and the thermodynamic information about the transition that can be gained from shock measurements.

It has been pointed out earlier[7] that the Hugoniot curve in the vicinity of the transition will have the qualitative features shown in Fig. 1 and that under certain conditions two shock waves moving at different velocities may be expected. It will be shown that knowledge of the slope of the Hugoniot segment above point A and the isothermal compressibility below A provide considerable information about the thermodynamics of the transformation.

In the following discussion of a first-order transition it will be assumed that the pressure behind a shock in a metal is essentially hydrostatic; that is, that the strength of the material is negligible. In addition, it will be assumed that the shock is moving into a semi-infinite medium. This imposes as a boundary condition the absence of lateral strain. H_1 and H_2 and v_1 and v_2 refer to the specific enthalpies and volumes of phases 1 and 2 at the same temperature and pressure; and λ_B is the mass fraction of phase 2 present at point B. It is then clear that the expressions for the total specific enthalpy and volume in the region of mixed phases can

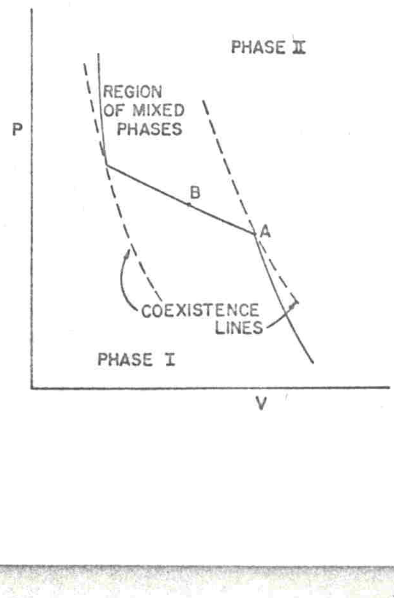

FIG. 1. Hugoniot curve and coexistence lines in the vicinity of a polymorphic transition.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Rice, McQueen, and Walsh, in *Solid State Physics, Advances in Research and Applications* (Academic Press, Inc., New York, to be published), Vol. 6.

[2] J. M. Walsh and R. H. Christian, Phys. Rev. **97**, 1544 (1955).

[3] F. S. Minshall, J. Appl. Phys. **26**, 463 (1955).

[4] H. Lawton and I. C. Skidmore, Discussions Faraday Soc., No. 22, 188 (1956).

[5] R. Schall, Z. angew. Phys. **2**, 252 (1950).

[6] Dapoigny, Kieffer, and Vodar, J. phys. radium **8–9**, 733 (1955).

[7] Bancroft, Peterson, and Minshall, J. Appl. Phys. **27**, 291 (1956).

[8] P. W. Bridgman, J. Appl. Phys. **27**, 659 (1956).