# Experimental Fusion Curves of Indium and Tin to 105 000 Atmospheres*†

J. DUANE DUDLEY‡ AND H. TRACY HALL
*Brigham Young University, Provo, Utah*
(Received December 18, 1959)

The experimental fusion curves of indium and tin have been determined to a pressure of 105 000 atmospheres. The melting point was detected at various pressures by means of a sharp increase in the electrical resistance of the sample, which gave rise to a sudden increase in the sample temperature. The melting temperature of indium was found to rise smoothly from a normal value of 156°C to a value of 417°C at 105 000 atm. The experimental data are fitted very well by the Simon equation $P/a=(T/T_0)^c-1$, with $a=15\,000$ atm, $c=4.34$, and $T_0=429$°K. No evidence of polymorphism is observed. A phase transition is found for tin, with a triple point on the fusion curve at 38 000 atm, 318°C. The melting temperature for the first phase rises smoothly from its normal value of 232°C to the triple point, and the data are fitted very well by the Simon equation with $a=7400$ atm, $c=11.3$, $T_0=505$°K. The melting temperature for the second phase rises smoothly from the triple point to a value of 500°C at 105 000 atm, and the data are fitted very well by the Simon-type equation $(P-38\,000)/21\,800=(T/591)^{5.25}-1$. The uncertainty is estimated to be approximately ±5% in the measured melting temperature, ±5% in the pressure calibration, ±20% in the Simon coefficient $a$, and ±2% in the Simon exponent $c$.

## INTRODUCTION

SEVERAL attempts have been made in the past to theoretically predict the nature of fusion curves at high temperatures and pressures. The most notable have been those of Lindemann,[1] Lennard-Jones and Devonshire,[2] Domb,[3] de Boer,[4] Salter,[5] and Gilvarry.[6] Of particular interest in the foregoing treatments are their theoretical justifications of a semiempirical fusion curve first proposed by Simon,[7] which has had remarkable success in fitting the experimental data of a wide variety of substances. This curve takes the form $P/a=(T/T_0)^c-1$, where $T$ is the melting temperature at pressure $P$, $T_0$ is the intersection of the fusion curve with the temperature axis, or essentially the normal melting point, and $a$ and $c$ are empirical constants, taken to be closely related to the "internal pressure" and interatomic forces, respectively. The Simon equation was originally thought to be valid only for the frozen inert gases, but recent experimental work with metals[8–10] has clearly demonstrated its validity in this area as well.

With the development of a new super-pressure apparatus[11] capable of generating pressures in excess of 100 000 atmospheres simultaneously with temperatures up to about 3000°C, it was felt that significant contributions could be made to the problem of fusion curves of metals. Indium and tin were chosen for the first experiments because of their relatively low normal melting points, malleability, low reactivity, and (in the case of tin) promise of interesting behavior with respect to polymorphism. This paper presents the detailed data of these experiments.

## APPARATUS

The tetrahedral-anvil apparatus, which was used in these experiments, has been adequately described with photographs and diagrams in other papers.[11,12] In essence, four cemented-tungsten-carbide anvils, with equilateral triangular faces, are driven simultaneously against the four faces of a pyrophyllite[13] sample-holder shaped in the form of a regular tetrahedron (see Fig. 1). The edge length of the pyrophyllite tetrahedron is 25% greater than the edge length of the triangular face of each anvil (being $\frac{15}{16}$ in. and $\frac{3}{4}$ in, respectively, in the experiments described below). Because of this, some of

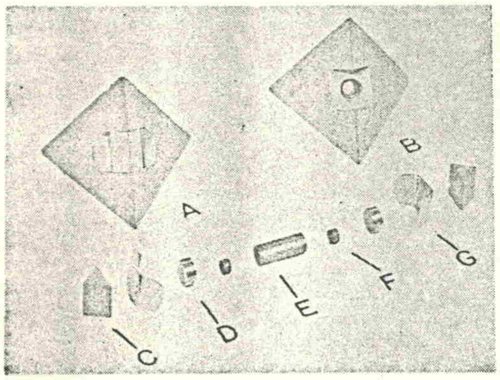


FIG. 1. Pyrophyllite sample-holder and assembly.

* This work was supported by the National Science Foundation
† Part of a thesis submitted in October, 1959, by J. D. D. in partial fulfillment of the requirements for the Ph.D. degree in physics at the University of Utah.
‡ Present address: Applied Research Division, Sandia Corporation, Albuquerque, New Mexico.

1 F. A. Lindemann, Physik. Z. **11**, 609 (1910).
2 J. E. Lennard-Jones and A. F. Devonshire, Proc. Roy. Soc. (London) **A169**, 317 (1939), and **A170**, 464 (1939).
3 C. Domb, Phil. Mag. **42**, 1316 (1951).
4 J. de Boer, Proc. Roy. Soc. (London) **A215**, 4 (1952).
5 L. Salter, Phil. Mag. **45**, 369 (1954).
6 J. J. Gilvarry, Phys. Rev. **102**, 308, 317, 325 (1956).
7 F. Simon and G. Glatzel, Z. anorg. u. allgem. Chem. **178**, 309 (1929). See also F. Simon, Trans. Faraday Soc. **33**, 65 (1937).
8 F. Simon, Nature **172**, 746 (1953).
9 H. M. Strong, J. Geophys. Research **64**, 653 (1959).
10 H. M. Strong and F. P. Bundy, Phys. Rev. **115**, 278 (1959).
11 H. T. Hall, Rev. Sci. Instr. **29**, 267 (1958).
12 H. T. Hall, Sci. American **101**, 61 (November, 1959).
13 This is a hydrous aluminum silicate, $Al_2O_3\cdot 4SiO_2\cdot H_2O$, sometimes known as Tennessee Grade-A Lava.