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Shock Compression of Solid Argon*

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The Hugoniot of solid argon (initially at 75°K and approximately 1 bar) has been determined using standard shock-wave techniques. Sample pressures ranged 18–645 kbar with associated densities of 1.39–2.18 times the initial density of 1.65 g/cc. Utilizing an exp-6 interatomic potential, a computed fit was obtained which was in excellent agreement with the data up to 300 kbar. The deviation between theoretical and experimental Hugoniot above 300 kbar is interpreted as either due to melting or to an inadequate model and potential form.

I. INTRODUCTION

The rare gases are elements whose physical properties are most easily interpreted theoretically because they are inert and form molecular crystals. Some recent investigations have extended equation-of-state data for argon[1–3] and xenon[4] by shock compression methods to pressures and temperatures not readily reached in static measurements. As a result of the high compression, the repulsive part of the interatomic potential can be measured for widely varying interatomic separations. Also a density region can be reached where electronic redistribution affects the properties predicted by simple theories.

The shock compression measurements of van Thiel and Alder[2] on liquid argon (samples initially at 86°K, 2 bar and at 148°K, 70 bar) indicate the repulsive part of the potential is much softer than that of the Lennard-Jones and Devonshire (LJD) (6–12) potential.[5] The measurements also indicated that the relevant parameters describing a simple potential are slightly dependent on the density region explored. Similar shock compression measurements by Keeler *et al.*[4] on xenon indicate a Hugoniot similar to that of argon when analyzed on a corresponding states basis except at the very highest pressures (approx. 500 kbar in xenon), where a substantial departure is encountered.

This deviation has been explained by Ross and Alder,[6] and in more detail by Ross,[7] on the basis of differences in the behavior of the electronic band structure at the higher densities. At the highest pressures, the xenon Hugoniot indicates a change in the compressibility due both to an electron population of the conduction band at the high temperatures reached and to a narrowing band gap. The band gap is not expected to narrow in argon at the highest shock pressures (approx. 350 kbar) and the temperature reached is not sufficient to populate the conduction band.

Based on their liquid-argon measurements van Thiel and Alder[2] indicate that, in the pressure–volume plane, the Hugoniot crosses the liquidus curve into the mixed phase region at about 0.7 kbar and re-enters the liquid phase at 45 kbar. Further calculations indicate the possibility of tracing out the melting line by starting

TABLE I. Solid argon Hugoniot data.[a]

Shock velocity (km/sec)	Particle velocity (km/sec)	Pressure (kbar)	Volume (cc/mol)	2024 Aluminum shock velocity (km/sec)	V/V0
2.00±0.01	0.56±0.08	19±3	17.41±0.99	5.84±0.06	
2.44±0.01	0.78±0.06	32±3	16.44±0.63	6.04±0.05	
2.68±0.02	0.94±0.08	42±3	15.71±0.68	6.19±0.06	
3.53±0.02	1.29±0.06	75±4	15.35±0.44	6.54±0.05	
4.17±0.02	1.78±0.06	122±4	13.90±0.36	7.03±0.06	
5.02±0.06	2.28±0.06	188±5	13.22±0.34	7.57±0.06	
5.31±0.01	2.35±0.02	206±2	13.48±0.10	7.67±0.02	
5.69±0.04	2.49±0.09	233±9	13.56±0.41	7.83±0.09	
6.13±0.07	3.02±0.03	305±4	12.30±0.22	8.38±0.03	
6.75±0.03	3.32±0.02	370±3	12.30±0.12	8.74±0.02	
7.21±0.03	3.60±0.05	428±6	12.13±0.19	9.05±0.05	
7.65±0.02	3.99±0.05	503±7	11.57±0.17	9.48±0.05	
8.49±0.07	4.60±0.06	645±9	11.09±0.22	10.17±0.05	

[a] Initial density is 1.65 g/cc at 75°K.

with argon at differing initial temperatures. In particular, the solid argon Hugoniot at 20°K is expected to cross the melting line between 160 and 330 kbar.[8]

In the present paper, measurements on the Hugoniot of solid argon (initially at 1 bar and 75°K) are reported. The higher initial density of the solid compared to the liquid has the advantage of permitting measurements to higher pressures. Also, by starting with the solid, the added complications produced by the Hugoniot crossing the melting line twice at low pressures would be avoided.[2] Additionally, the determination of a point on the melting curve could possibly be detected by a discontinuous change in slope in the shock velocity (U_s)–particle velocity (U_p) relation.

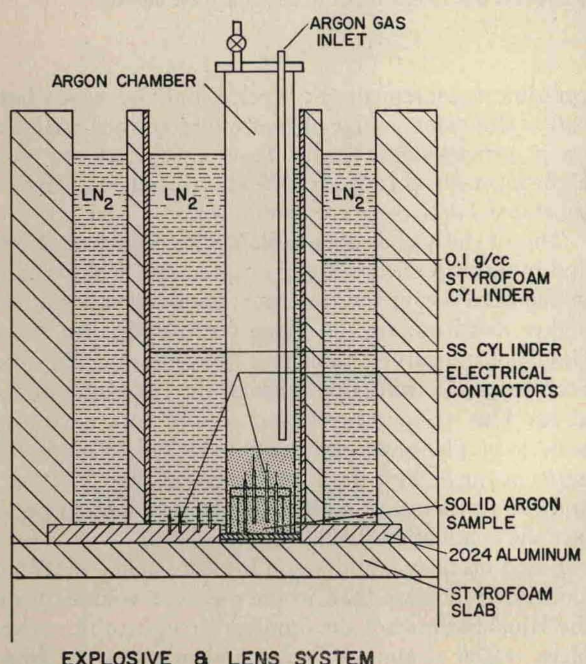

FIG. 1. Cross-sectional view of the apparatus used for the solid argon experiments.

II. EXPERIMENTAL APPARATUS

The experiments consisted of measuring the shock velocities in argon samples and in 2024 aluminum standards. The shock velocity was varied by appropriate choices of the explosive system, and was measured by the electrical pin-contactor technique. The experimental apparatus is shown in Fig. 1. The argon chamber is constructed alternatively from either a Pyrex glass tube or a stainless-steel cylinder closed at the sample end by a 2024 aluminum cover. After flushing with argon gas (99.99% pure), the solid sample is formed by slowly lowering the chamber into a liquid nitrogen bath. A visual inspection revealed the solid argon to be homogeneous, clear, and free of vapor snakes.

Since argon is nonconducting, coaxial electrical pin contactors[9] were placed in both the sample and the standard. The pin positions were measured at room temperature and corrections were made for thermal contraction to 75°K. For the solid argon, the pins were mounted in a disk supported above the 2024 aluminum cover. The solid was then allowed to grow around the pins in apparent intimate contact. In all cases, the distance between the lowest and highest pin levels was kept as small as possible (approx. 3 mm) in order to minimize the effects of attenuation on the pressure pulse. For this same reason, it was necessary to fit the argon sample holder into a recess in the 2024 aluminum plate. The insulating styrofoam slab shown in Fig. 1 was removed a few seconds before the explosive was detonated, allowing the aluminum plate to rest directly on the explosive.

III. RESULTS AND INTERATOMIC POTENTIAL

The Hugoniot data of the solid argon are presented in Table I. From measured shock velocities in the sample