PROBLEM OF THE EXISTENCE OF A METALLIC STATE IN DYNAMICALLY COMPRESSED CARBON

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A metallic phase of dynamically compressed carbon, as reported by Alder and Christian,[1] was not observed. Measurements were carried out on special graphite samples, 70 mm thick, in order to eliminate the scale factor.

ALDER and Christian[1] reported the results of a study of the dynamic compressibility of graphite (initial density $\rho_0 = 1.7$ and 2.1 g/cm^3) up to pressures of ~900 kbar. Using the experimentally obtained pressure-volume relationship P(v), Alder and Christian concluded that shock compression of graphite produced, in addition to the diamond phase, a denser metallic phase. According to their data, the diamond phase existed in the pressure range from ~400 to ~550 kbar. The transition to the metallic state occurred at higher amplitudes of the shock waves. The maximum density of shock-compressed carbon, reported in[1], was ~4.5 g/cm^3, which was more than twice the intial density.

At the same time, various groups in the USSR[2,3] carried out independent investigations of the compressibility and the equation of state of carbon in a wide range of pressures. The experimental results of all investigators practically coincided at pressures up to ~550 kbar. At higher pressures, the results did not agree: in contrast to the data of Alder and Christian,[1] Pavlovskiĭ and Drakin[2] and Krupnikov[3] did not observe experimentally a metallic phase of carbon right up to pressures of ~3 Mbar. Moreover, no metallic phase was found in the shock compression of natural diamond.[2]

The cause of this disagreement, apart from the possibility of experimental errors, may be the "scale factor" which is the ratio of the transformation time to the characteristic time of the recording apparatus. Obviously, investigations carried out on samples of greater thickness should make it possible to record later stages of a phase transformation. A dependence of the amplitude characteristics of the shock wave on the thickness of the investigated graphite samples was observed experimentally in all investigations. This stimulated Pavlovskiĭ and Drakin[2] to carry out additional measurements of the compressibility using thicker samples of graphite (~10 mm) but again they did not find a metallic state of carbon.

With the same purpose in mind, we measured the dynamic compressibility of graphite using shock pressures P ~ 620 kbar and much thicker samples: we employed a sample of chemically pure graphite whose initial density was $\rho_0 = 1.878$ g/cm^3 and which was 70 mm thick. The ratio of the diameter to the thickness was four. The compressibility of the graphite was determined by the reflection method[4] under conditions close to those described in[5]. The sample under investigation was placed behind a 40-mm thick aluminum screen and an aluminum block 160-mm thick. We determined experimentally the wave velocities D in a control block made of aluminum, as well as in graphite. The contacts used to record the actual moment of passage of a shock wave were placed at the screen-aluminum and aluminum-graphite boundaries as well as on the free surface of the graphite sample. At each recording surface, we used four contacts placed at the same distances from the center along two mutually perpendicular directions. The time intervals, found using the two pairs of opposite contacts, did not differ by more than 1%.

The wave velocities were converted into other compression parameters as follows: in the case of aluminum we used its known dynamic adiabat,[9] but for graphite we employed the standard method of plotting the pressure-mass velocity U diagram. Making small corrections for the attentuation of the shock wave in aluminum and graphite, we obtained the following results reduced to the mid-plane of the graphite sample:

$$D_{Al} = 9.75 \text{ km/sec}, \quad U_{Al} = 3.31 \text{ km/sec}, \quad P_{Al} = 0.874 \text{ Mbar}$$
$$D_C = 8.13 \text{ km/sec}, \quad U_C = 4.03 \text{ km/sec}, \quad P_C = 0.615 \text{ Mbar}$$
$$v_C = 0.2685 \text{ cm}^3/\text{g}.$$

The error in the determination of the wave velocities in graphite did not exceed ±1% and the error[5] in the determination of the degree of compression was

$$\Delta\sigma = \sigma(\sigma-1)\left[\left(\frac{\Delta D}{D}\right)^2+\left(\frac{\Delta U}{U}\right)^2\right]^{1/2} = \pm 0.03.$$

Here, $\sigma = v_0/v$, $v_0 = 0.531$ cm^3/g, and consequently, $\Delta v = \pm 0.004$ cm^3/g.

The experimental point on the pressure-specific volume diagram, obtained in the present investigation, was compared with the results reported in[1] and[2] (cf. Fig. 1). Its position, which was very close to the diamond adiabat, undoubtedly indicated that, in this range of pressures, only the tetragonal modification of carbon was present. Therefore, in agreement with[2,3], the experimental results of Alder and Christian referring to the metallic state of carbon must be regarded as erroneous: in spite of the high degree of compression and high temperatures, the tetrahedral configuration of carbon atoms is thermodynamically stable under these conditions. Obviously, the results of Alder and Christian were obtained using extremely large recording base lengths, including the unloaded region of the shock-wave trajectory.

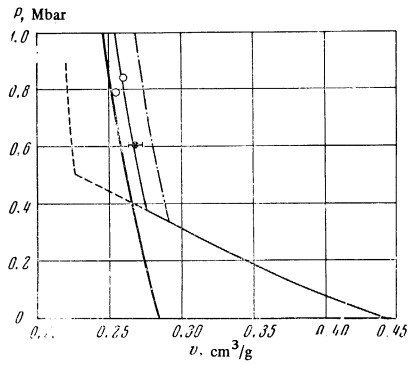

FIG. 1. P–v diagram of shock compression of carbon: ●– our results; ○ and thin continuous line represent the results of Pavlovskiĭ and Drakin, [2] obtained using samples $\Delta \sim 10$ mm thick; the chain line represents their results for samples $\Delta \sim 4$ mm thick; the dashed line is the approximation of the results Alder and Christian [1] at $P > 0.4$ Mbar; the thick line is the dynamic adiabat of iron given in [2].

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