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Interaction of Rare-earth Element Oxides with Boron in Shock Compression

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The action of shock waves on lanthanum, neodymium, gadolinium, yttrium, and ytterbium oxides and their mixtures with amorphous boron has been investigated. It has been shown that the processes which occur, namely, the phase transformations of the oxides and the formation of hexaborides, are determined completely by the high temperatures produced in the ampoules acting on the high proportion of structural defects in the substance, caused during the passage of the shock-wave front. Shock compression of the specimens under conditions which hinder the production of high residual temperatures does not lead to chemical processes; however, when the residual defect nature of the specimens is retained the mobility of the atoms in the crystal lattice of the substance is greatly increased.

Shock compression of the substance in cylindrical pressure ampoules produces high residual temperatures, owing both to the non-adiabatic nature of the dynamic compression, and to the macroplastic flow of the substance[1]. This enables the confining of a substance in cylindrical ampoules to be used for making preparations requiring a high temperature.

We have studied the possibility of obtaining by this method rare-earth element (r.e.e.) borides which are usually made by heating mixtures of the r.e.e. oxides with elemental boron in a vacuum.

Lanthanum, neodymium, and gadolinium oxides of high purity with $\geq 0.05\%$ other r.e.e. and "pure" grade amorphous boron were used. We also investigated the effect of shock compression on pure yttrium and ytterbium oxides themselves. The oxides were first heated at 1100°C when they corresponded to the A form for lanthanum and neodymium and the C form for gadolinium, yttrium, and ytterbium. The product after shock compression was examined by X-ray phase analysis with a URS-60 apparatus and RKD X-ray cameras. Filtered copper radiation was used. The X-ray diagrams were measured on an IZA-2 comparator and corrections for absorption were made by the Gadding method. The shock action was produced by the method already described[2]; charges of granular hexagen and cast TG 40/60 were used. The specimens were confined in copper and in iron ampoules. The degree of filling of the ampoules, that is, the relation of the bulk density to the pyknometric, was 0.5–0.6. Mixtures of r.e.e. oxides and boron in the molar ratios 1:2 and 1:15 respectively were subjected to shock compression.

We first investigated the action of shock waves on the pure oxides, since the available information[3] relates only to the shock compression of their C forms and the method then employed[3] differed from ours. We showed that the action of shock waves on the A forms of neodymium and lanthanum oxides does not lead to any structural changes in these substances. The diffraction reflections on the X-ray diagrams of the products of shock compression were appreciably less diffuse than those for the initial substances. Unlike the results of Ruchkin and coworkers[3] our shock compression of the C-form of gadolinium oxide even with the weaker charge of granular hexagen led to complete conversion into the B form of this oxide (see Figure). Its X-ray diagram had sharp X-ray reflections. Shock compression of the C form of yttrium and ytterbium oxides also (again unlike Ruchkin's work[3]) did not lead to any residual structural changes. The quality of the X-ray diagrams of the products after the shock compression had improved significantly.

The sharpness of the X-ray diagrams of the products after shock compression, although an increase in the number of defects was to be expected after the passage of a shock wave, shows that the temperatures realised were close to the melting point of the oxides being investigated (1900–2400°C). This assumption and our results agree well with the scheme interpreting the interaction of polymorphic modifications of r.e.e. oxides given by Warshaw and Roy[4]: after reaching the melting point, irrespective of the initial form, lanthanum and neodymium oxides should crystallise in the A form, gadolinium oxide in the B form, and yttrium and ytterbium oxides in the C form.

An X-ray diffraction investigation of the products of shock compression of the mixtures of oxides and lanthanum, neodymium, and gadolinium with amorphous boron showed the formation of the hexaborides of the corresponding elements in every instance. The radial distribution of the products in the ampoules which is characteristic for all the experiments is noteworthy. Two sharply demarcated concentric zones are observed. The inner zone—the "cord"[2]—the presence of up to 2 mm in diameter, consisted of r.e.e. hexaboride, almost pure except possibly for some amorphous boron, which cannot be detected by X-ray diffraction. As an example, the Figure gives the X-ray diagram of a specimen extracted from the "cord". The same Figure also shows the powder diagram of a specimen of a shock-compressed mixture of boron and lanthanum oxide taken from the mass surrounding the "cord". In this instance, in addition to the lines of