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Abstract

Full Text

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PHYSICS

Academician **L. F. VERESHCHAGIN**, **A. A. SEMERCHAN**,
N. N. KUZIN, **Yu. A. SADKOV**

CHANGE IN THE ELECTRICAL RESISTANCE OF Rb, Cs AND Ca UNDER PRESSURE

Balchan and Drickamer (¹) proposed a number of reference points for the high-pressure scale in the region from 100 kbar and above. The reference points adopted were the pressure values at which the onset of a sharp increase in the electrical resistance of iron, barium, lead, and rubidium takes place (respectively 133, 144, 161, and 193 kbar), as well as the pressure values at which maxima are observed on the curves of the pressure dependence of the resistance of calcium and rubidium (respectively 375 and 425 kbar). Since the maxima are rather broad, the jump-like change in the resistance of rubidium at 193 kbar is, according to Balchan and Drickamer's data, the highest reference point with a clearly expressed character.

The investigations were carried out in a three-stage high-pressure apparatus that we constructed and described earlier (²) (more precisely, in a somewhat modified version of it). The apparatus has a substantial working volume (~0.25 cm³). Calibration of the apparatus with respect to pressure was carried out at 20° using bismuth, tin, barium, and lead. The calibration curve is shown in Fig. 1. As can be seen from the figure, the section of the curve in the pressure range 24.5–161 kbar is a straight line. The accuracy of pressure determination is $\pm 4\%$.

Fig. 1. Calibration curve of the three-stage apparatus with respect to pressure

In Fig. 2a a curve is shown for the pressure dependence (and dependence on pressure) of the electrical resistance of Rb, obtained at 20°. As can be seen from the figure, the resistance has a minimum value at ~20 kbar, the first (small) jump at 75 kbar, and a second (substantial) jump beginning at 135–140 kbar.

Fig. 2

Figure 2: Fig. 2

Bandy (3), studying the P – T diagram of rubidium on a “belt” apparatus, found that at room temperature and a pressure of 75–80 kbar a jump-like increase of its resistance by 8–10% is observed. Balchan and Drickamer could not detect an analogous jump. They explained this by the rapid increase of the resistance of Rb with pressure and by difficulties arising in their setup at pressures in this region. Thus, we have for the first time confirmed the existence of a jump in the resistance of Rb at ~ 75 kbar. The jump is completely reversible (Fig. 2b). The curve presented in Fig. 2b was obtained on a high-pressure apparatus having a working volume of $\sim 0.5 \text{ cm}^3$ (4).

As indicated above, Balchan and Drickamer found a sharp increase in the resistance of Rb at a pressure of 193 kbar (the accuracy of the pressure determination is not given). E. S. Alekseev and R. G. Arkhipov (5), using the Thomas–Fermi statistical potential in the Wigner–Seitz problem, calcu-

gave the pressure of the electronic transition in rubidium (from the $5s$ shell to $4d$). It turned out to be ~ 200 kbar. In their opinion, there are grounds to assume that the jump in resistance at 193 kbar, found by Balchan and Drickamer, is associated with the indicated electronic transition.

As was indicated earlier, we also found an analogous step-like increase in resistance (the second jump), but at a considerably lower pressure (135–140 kbar). The transition is completely reversible (Fig. 2a).

Fig. 2. Change with pressure of the electrical resistance of rubidium (a and b), cesium (c) and calcium (d). I –increase of load, II –decrease of load

We believe that the calculation data of E. S. Alekseev and R. G. Arkhipov in work (5) agree satisfactorily with our data, since these calculated data can hardly claim great accuracy. Thus, this is already the second case of our disagreement in estimating the magnitude of the pressure of the reference points proposed by Balchan and Drickamer. Earlier we reported that the onset of the increase in the resistance of iron is observed not at 133 ± 3 kbar, but at 150 ± 6 kbar (6).

One of the possible reasons for the discrepancy (apart from the difference in the magnitude of the working volumes) could have been a difference in the degree of purity of the materials investigated. We carried out studies with rubidium containing impurities

(in %): K 2.2, Na 0.07, Ca 0.02. In the case of using less pure material (K 4.54, Na 0.05, Ca 0.03, Cs 0.25), the first and second jumps were observed at approximately the same pressure values (within the experimental error). Balchan and Drickamer do not indicate the degree of purity of their samples.

Since the reference point of rubidium turned out to be lower than the reference

Fig. 3. Calibration curve of the four-stage pressure apparatus

Figure 3: Fig. 3. Calibration curve of the four-stage pressure apparatus

point of lead, it was of interest to investigate the pressure dependence of the resistance of other metals in order to find new reference points.

At present, similar work is being carried out, the results of which will be published later. Of the metals already investigated, in our opinion cesium is of undoubted interest (see Fig. 2b). As is seen from the figure, after the first maximum at ~ 42 kbar, found earlier by Bridgman ⁽⁷⁾, there follows a sharp increase in the resistance of cesium, beginning at 120–125 kbar, and a second maximum at 140–145 kbar. An analogous jump in resistance was observed by Stager and Drickamer ⁽⁸⁾, but not at 120–125 kbar, rather at 175 kbar. This is the third case of a significant discrepancy in estimating the pressure at which a jump-like change in the resistance of certain metals begins. The material investigated by us had impurities (in %): K 0.5, Ca 0.1, Na 0.05, Rb 1.0. Stager and Drickamer worked with cesium having a purity of 99.95%.

Fig. 3. Calibration curve of the four-stage pressure apparatus

Rb and Cs samples in the form of thin wire 0.5 mm in diameter, obtained with the aid of a medical syringe by extrusion in transformer oil, were placed in the axial hole of an AgCl cylinder, which served as the medium transmitting the pressure to the sample. The cylinder had a diameter of 3 mm and a height of 5 mm. The axis of the cylinder coincided with the direction of application of the press force. Electrical contact of the sample with the punches was made by means of platinum caps of special shape, which fitted tightly into the hole filled with rubidium or cesium.

In order to check the calcium reference point, we constructed a four-stage high-pressure apparatus, since the upper pressure limit of the three-stage apparatus is $\sim 200 \div 220$ kbar.

Figure 2a presents the pressure dependence (and the dependence on the press force) of the electrical resistance of calcium of grade TU MKhP 3360-55. As is seen from the figure, the curve has a gentle maximum (according to Balchan and Drickamer, at 375 ± 15 kbar).

From comparison of Figs. 2a and 3, we find that the calcium reference point fits well on the calibration curve (provided the curve is linear in the interval 24.5–375 kbar).

The apparatus has a working volume of ~ 0.2 cm³. The samples were arranged in the high-pressure cell in the same way as in the experiments with Rb and Cs.

Institute of High Pressure Physics
Academy of Sciences of the USSR

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