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# On the Identification of New and Normal Phases in the System of Cadmium–Antimony Alloys<sup>2</sup>)

By

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A set of Cd–Sb alloy samples of concentrations 7, 20, 37, 48, 50, 52, and 70 at% Sb are prepared in evacuated silica tubes at 900 °C. The X-ray diffraction analysis of some annealed samples shows a metastable phase, which is not previously identified by other workers. After studying decomposition and its crystal structure this phase is given the chemical formula  $Cd_5Sb_4$  and a unit cell of orthorhombic shape with dimensions of 0.7309, 0.5427, and 0.506 nm for *a*, *b*, and *c*, respectively. The other phases Cd, Sb, CdCb, and  $Cd_4Sb_3$  are identified in both, quenched and annealed samples. Electron diffraction and metallurigical studies are used in the identification. Contradictions in the phase diagram of the Cd–Sb system are discussed.

Ein Satz von Cd-Sb-Legierungsproben mit Konzentrationen von 7, 20, 37, 48, 50, 52 und 70 At% Sb werden in evakuierten Silikatglasröhrehen bei 900 °C präpariert. Die Röntgenbeugungsanalyse einer getemperten Probe zeigt eine metastabile Phase, die bisher von anderen Autoren noch nicht identifiziert worden ist. Aus der Untersuchung der Zerlegung und der Kristallstruktur wurde diese Phase durch die chemische Formel  $Cd_5Sb_4$  gegeben mit einer rhombischen Einheitszelle, deren Dimensionen 0,7309; 0,5427 bzw. 0,506 nm für a, b, bzw. c betragen. Die anderen Phasen Cd, Sb, CdSb und  $Cd_4Sb_3$  werden sowohl in abgeschreckten als auch in getemperten Proben identifiziert. Elektronenbeugung und metallurgische Untersuchungen werden zur Identifizierung herangezogen. Auftretende Widersprüche im Phasendiagramm des Cd-Sb-Systems werden diskutiert.

# 1. Introduction

Cadmium-antimony compounds have attracted the attention of numerous scientific investigators [1 to 3]. The phase diagram of stable and metastable equilibrium in the Cd-Sb system was studied by thermographic, metallographic, and X-ray diffraction methods in the concentration range 3 to 43 wt% Sb [4]. On the basis of the Cd-Sb system in the concentration interval 49.83 to 80.42 at% Sb a phase of variable compound was formed [5]. Different phases were identified in the phase diagram of the CdSb system by other workers [6 to 11].

The aim of the present work is to perform a detailed study on the materials of the Cd–Sb alloy system. This will include formation, transformation or decomposition, and stability ranges of different phases within that system. When necessary a crystal structure investigation of new phases is given. The main techniques used here are X-ray diffraction analysis, electron diffraction, and metallographic investigations.

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## 706 A. A. MOHAMED, S. A. SALEH, E. A. ABOU-SAIF, M. ABD-RABO, and G. A. EL-GANAINY

# 2. Experimental Procedure

A double set of Cd–Sb alloy samples of concentrations 7, 20, 37, 48, 50, 52, and 70 at% Sb were prepared. The composition of these samples was chosen to represent the most important features and critical points in the phase diagram of the system given by Hansen [12]. For this purpose, spec materials of Cd and Sb of purity 99.999% were used. The weighed mixtures of the pure components representing the abovementioned compositions were inserted in evacuated silica tubes. The tubes after being sealed were heated slowly in a muffle furnace up to a temperature of 900 °C and kept for a soaking time of 4 h at that temperature. One set of the samples was quenched in air, while the other set of the same concentrations was furnace-cooled, i.e. annealed. The samples could be tabulated in Table 1.

Table 1

Quenched and furnace-cooled samples of different Sb contents

samples	quenched							furnace-cooled							
	1 <sub>q</sub>	$2_{\mathbf{q}}$	$3_{\mathbf{q}}$	$4_{\mathbf{q}}$	$5_q$	6 <sub>q</sub>	$7_q$	$l_{f}$	$2_{f}$	$3_{f}$	$4_{f}$	$5_{\mathbf{f}}$	$6_{\mathbf{f}}$	$7_{f}$	
Sb (at%)	7	20	37	48	50	52	70	7	20	37	48	50	52	70	

Structural investigation of powders from both sample sets was carried out by X-ray diffraction techniques. A Philips X-ray diffractometer was used. The radiation used was  $\operatorname{CuK}_{\alpha}$  ( $\lambda = 0.154178$  nm) with Ni filter. For electron diffraction examination, the suspension technique was adapted. An ELMI D2 electron microscope from GDR was utilized. The high voltage used was 45 kV. A backreflected-light large-field microscope for the examination of plane and polished sections of type Leitz Metallux 887651 (FRG) was used for surface investigation of the samples. Heat treatment regimes were applied on some furnace-cooled samples.

# 3. Results

# 3.1 Quenched samples

The X-ray diffraction patterns of quenched powder samples  $l_q$  and  $2_q$  are shown in Fig. 1 a and b; those of  $3_q$  are shown in Fig. 2, while the patterns of samples  $4_q$ ,  $5_q$ ,



Fig. 1. X-ray diffraction patterns of quenched samples: a)  $l_q$ , b)  $2_q$ 



Fig. 2. X-ray diffraction pattern of quenched sample  $3_q$ 

 $6_q$ , and  $7_q$  are given in Fig. 3 a, b, c, and d, respectively. The analysis showed that the Cd phase appeared in samples  $1_q$ ,  $2_q$ ,  $3_q$ ,  $4_q$ , and  $5_q$ , while the Sb phase appeared in samples  $4_q$ ,  $5_q$ ,  $6_q$ , and  $7_q$ . The stable phase CdSb was found as a trace in sample  $2_q$ , minor in samples  $3_q$  and  $7_q$ , and as a major component in samples  $4_q$ ,  $5_q$ , and  $6_q$ . The metastable phase Cd<sub>4</sub>Sb<sub>3</sub> was found as a trace in samples  $2_q$  and as a major component in samples  $3_q$ , then disappeared completely in samples of higher Sb content and reappeared only in sample  $7_q$ .

The microstructure of quenched samples showed the presence of different phases. Fig. 4 a and b show the structure of samples  $2_q$  and  $7_q$ , respectively, as representative photographs. Fig. 4a reveals the presence of Cd in the form of bright grains and Cd<sub>4</sub>Sb<sub>3</sub> phase as a dark matrix. Fig. 4b illustrates that the matrix is composed of Sb as dark grains with parallel striations and the bright grains represent both Cd<sub>4</sub>Sb<sub>3</sub> and CdSb phases.

The spot electron diffraction patterns were investigated in case of quenched samples indicating the presence of the phases with large crystalline size (see, e.g. Fig. 5 a and b for samples  $5_q$  and  $6_q$ ). It was found that a single phase is present in sample  $2_q$  as



Fig. 3. X-ray diffraction patterns of quenched samples: a)  $4_q$ , b)  $5_q$ , c)  $6_q$ , d)  $7_q$ 

708 A. A. MOHAMED, S. A. SALEH, E. A. ABOU-SAIF, M. ABD-RABO, and G. A. EL-GANAINY



Fig. 4. The surfcae structure of quenched samples: a)  $2_q,\,$  b)  $7_q$  (Magnification:  $250\times)$ 

Fig. 5. The electron diffraction patterns of quenched samples: a)  $5_q$ , b)  $6_q$ 

 $Cd_4Sb_3$ . Meanwhile, single phases CdSb are present in samples  $3_q$ ,  $5_q$ , and  $6_q$  and Sb is present in sample  $7_q$  as a single crystalline phase.

# 3.2 Furnace-cooled samples (annealed)

Fig. 6 shows the X-ray diffraction pattern of sample  $l_f$ . Cd is present here as a minor phase. However, most of the obtained diffraction lines especially those of strong,



Fig. 6. X-ray diffraction pattern of furnace-cooled sample: (i.e. annealed)  $I_{\rm f}$ 

relative intensities are not belonging to any known phase of the CdSb system. Thus, they correspond to the unknown phase which was also identified as a major phase in sample  $2_{\rm f}$ . Fig. 7 shows the diffraction pattern of sample  $2_{\rm f}$  in which 7a represents the original sample, 7b corresponds to the fine powders, and 7c for coarse particles.



The addition of patterns 7b and 7c will form the pattern 7a. It was found that sample  $2_{\epsilon}(b)$  is composed of Cd as a major phase beside the presence of the metastable phase  $Cd_4Sb_3$  and the stable one CdSb. The sample  $2_{f}(c)$  shows the presence of the unknown phase as essential constituent. This phase disappeared completely from other furnace-cooled samples (see Fig. 8 for the X-ray diffraction pattern of  $3_{f}$  and Fig. 9 a to d for samples  $4_f$  to  $7_f$ , respectively). Its disappearance gives rise to the formation of both Cd<sub>4</sub>Sb<sub>3</sub> and CdSb phases. This fact gives indication that it decomposes into the phases mentioned and might have the formula Cd<sub>5</sub>Sb<sub>4</sub>, while its decomposition can be expressed by the following equation:

$$\operatorname{Cd}_5\operatorname{Sb}_4 \to \operatorname{Cd}_4\operatorname{Sb}_3 + \operatorname{CdSb}$$
. (1)

Fig. 7. X-ray diffraction patterns of furnace-cooled sample  $2_{f}$ : a) Original sample, b) fine part of the sample, c) coarse part of the sample



710

Fig. 8. X-ray diffraction pattern of furnace-cooled sample  $3_{\rm f}$ 

From Fig. 8 and 9 a to d, it was found that the Cd phase is present as a minor one and trace in samples  $3_f$ ,  $4_f$ , and  $5_f$ , while the Sb phase exists as a minor one in samples  $4_f$ ,  $5_f$ ,  $6_f$  and as a major one in  $7_f$ . Besides, in sample  $3_f$  the phase  $Cd_4Sb_3$  was present as a major constituent. This phase disappeared completely in samples of higher Sb content. The stable phase CdSb was found as minor one in samples  $3_f$  and  $7_f$  and as a major component in samples  $4_f$ ,  $5_f$ , and  $6_f$ .

The microstructure of the different phases of furnace-cooled samples was investigated and one of the representative photographs is given in Fig. 10 a to c for samples  $I_f$ ,  $5_f$ , and  $6_f$ , respectively. The bright grains represent the Cd phase and the dark matrix is due to the  $Cd_5Sb_4$  phase appearing in the form of an aggregate of irregular elongated, fine grains. In Fig. 10b the CdSb phase appears in the form of large grey grains with obvious striations, but without sharp grain boundaries in some places and perforated in several places. Cd appears here also as few high irregular grains, while Sb is found in the dark areas on the grain boundaries of the large CdSb crystallites. In Fig. 10c CdSb is present as a major phase in form of large grey grains of unsharp grain boundaries and the dark places are those belonging to Sb phase.



Fig. 9. X-ray diffraction patterns of furnace-cooled samples: a)  $4_{f}$ , b)  $5_{f}$ , c)  $6_{f}$ , d)  $7_{f}$ 



Fig. 10. The surface structure of furnace-cooled samples: a)  $1_{f}$  (250×), b)  $5_{f}$  (330×), c)  $6_{f}$  (330×)

On the other hand, it was found that the electron diffraction patterns of the furnacecooled samples  $3_f$ ,  $4_f$ , and  $5_f$  are composed of continuous rings indicating the presence of such samples in a polycrystalline structure of small crystallite size (e.g. see Fig. 11 for sample  $5_f$ ). The analysis of such a pattern indicates the presence of CdSb and Sb phases, while the patterns of  $3_f$  and  $4_f$  showed the existence of Cd<sub>4</sub>Sb<sub>3</sub>, CdSb, and Cd phases in  $3_f$  and CdSb, Cd, and Sb phases in  $4_{-}$ . The spot patterns were examined in case of samples  $6_f$  and  $7_f$  indicating the presence of single phase CdSb in these samples.



Fig. 11. The electron diffraction pattern of furnace-cooled sample  $5_{f}$ 

Ito's method [13] was used for the determination of lattice parameters of the unknown new phase  $Cd_5Sb_4$ . It is based on a determination of the reciprocal lattice of the investigated material. The following relation between  $r^*$  and d was used:

$$r^{*2} = \frac{1}{d_{(hkl)}^2} = h^2 a^{*2} + k^2 b^{*2} + l^2 c^{*2} + 2hka^* b^* \cos \gamma^* + 2klb^* c^* \cos \alpha^* + 2lhc^* a^* \cos \beta^* , \qquad (2)$$

where  $a^*$ ,  $b^*$ , and  $c^*$  are the linear parameters and  $\alpha^*$ ,  $\beta^*$ , and  $\gamma^*$  are the interaxial angles of the reciprocal lattice. The observed and computed  $Q_{hkl}$  of the phase  $Cd_5Sb_4$ were carefully determined from which the values of  $a^*$ ,  $b^*$ , and  $c^*$  were estimated as 0.13726, 0.17992, and 0.19761, respectively. The values of  $\alpha^*$ ,  $\beta^*$ , and  $\gamma^*$  were 90° and a = 0.7309 nm, b = 0.5427 nm, and c = 0.506 nm. This means that the crystal lattice of the  $Cd_5Sb_4$  phase is orthorhombic.

#### 3.3 Concentration and stability ranges of the identified phases

From the X-ray diffraction patterns and the interpretation of the obtained results, the stability ranges and maximum concentration of the identified phases were given. The relation between the concentration of a given phase versus composition of the examined alloy was drawn in individual curves showing the stability range of that phase (see Fig. 12 a to e for Cd,  $Cd_4Sb_3$ ,  $Cd_5Sb_4$ , CdSb, and Sb phases, respectively, in both quenched and furnace-cooled samples). It is quite clear to find unreacted Cd in samples having maximum concentration values of Sb.

The phase  $Cd_4Sb_3$  shows a similar trend in both sets. It disappears completely by increasing the amount of Sb, which may be due to its decomposition as follows:

$$Cd_4Sb_3 \rightarrow 3 CdSb + Cd$$
 . (3)

This explains the sudden increase in the amount of CdSb starting from sample 4. It also explains the appearance of Cd in samples 4 and 5 which cannot be due to non-reactivity of the pure component of the system, i.e. Cd, due to its regeneration according to the previous equation. It can be noticed that the metastable phase  $Cd_4Sb_3$  appeared again with an amount of 25% in sample  $7_q$ . This may be due to the reaction of the CdSb phase to form  $Cd_4Sb_3$  with obvious increase of the amount of Sb. This reaction can be explained by the following equation:

$$4 \operatorname{CdSb} \to \operatorname{Cd}_4 \operatorname{Sb}_3 + \operatorname{Sb} . \tag{4}$$



Fig. 12. Relations between Sb phase and relative concentrations of the phases: a) Cd, b) Cd<sub>4</sub>Sb<sub>3</sub>, c) Cd<sub>5</sub>Sb<sub>4</sub>, d) CdSb, e) Sb;  $\circ$  f,  $\bullet$  q

This results in the sudden decrease of the amount of CdSb and the simultaneous increase in Sb concentration.

Meanwhile, the maximum concentration of the  $Cd_5Sb_4$  phase occurs at the minimum concentration of Sb. Thus, this phase has a stability range of 7 to 20% Sb with maximum concentration at 7% Sb, while it disappears completely in samples of successive compositions.

The stability range and concentration of the CdSb phase are between 20 to 70% of Sb, having a maximum concentration in sample 6.

Starting from sample 4 of 48 at% Sb to sample 7 of 70 at% Sb the amount of free Sb shows a gradual increase and ranges from between 15 to 20 and 30 in samples 4,5, and 6. Then, it showed a sudden increase in sample 7. This phenomenon can be due to regeneration of Sb due to a sudden change of CdSb phase according to the following equation:

$$4 \operatorname{CdSb} \rightleftharpoons \operatorname{Cd}_4 \operatorname{Sb}_3 + \operatorname{Sb} \,. \tag{5}$$

This is obvious from the sudden decrease of CdSb in sample 6 to sample 7 accompanied by a sudden reappearance of  $Cd_4Sb_3$  and increase in Sb amount in the later sample.

## 3.4 The effect of heat treatment

Each of the investigated furnace-cooled samples was heated to a maximum temperature considerably lower than the liquidus line in the phase diagram of the system. After soaking the sample at the temperature 300 °C for 3 h, it was left to cool in the furnace and then examined by the X-ray diffraction method.

Fig. 13 a and b reveal the X-ray diffraction patterns of sample  $1_f$ , while Fig. 14 a to c show the X-ray diffraction patterns of samples  $3_f$ ,  $5_f$ , and  $7_f$ , before and after heat treatment.



Fig. 13. X-ray diffraction patterns of furnace-cooled sample  $l_f$  (a) before and (b) after heat treatment

It was found from Fig. 13 a and b that no changes occurred in the composition of sample  $l_f$ , except that the amount of the  $Cd_5Sb_4$  phase increased with simultaneous decrease of Cd. From Fig. 14 a to c it is clear that after heat treating sample  $3_f$  to 300 °C for 3 h, the  $Cd_4Sb_3$  phase disappeared completely accompanied by an obvious decrease in the amount of CdSb and the formation of the phase  $Cd_5Sb_4$ . This might suggest the following reaction to be undertaken during the heat treatment:

$$\operatorname{Cd}_4\operatorname{Sb}_3 + \operatorname{CdSb} \to \operatorname{Cd}_5\operatorname{Sb}_4.$$
 (6)

The phase  $Cd_5Sb_4$  represents the major phase in the heat-treated samples together with trace amounts of Cd and CdSb. While the X-ray diffraction analysis of the heat treated sample  $5_f$ showed the complete disappearance of both Cd and Sb as well as the presence of a major amount of  $Cd_5Sb_4$  and minor amount of CdSb.

The occurring reactions are rather difficult to be understood. However, they can be explained according to the following equations:

$$4 \operatorname{CdSb} \rightleftharpoons \operatorname{Cd}_4 \operatorname{Sb}_3 + \operatorname{Sb} , \tag{7}$$

$$Sb + Cd \rightarrow CdSb$$
, (8)

$$\operatorname{Cd}_4\operatorname{Sb}_3 + \operatorname{CdSb} \rightleftharpoons \operatorname{Cd}_5\operatorname{Sb}_4.$$
 (9)

On the other hand, the X-ray diffraction analysis of heat-treated sample  $7_f$  showed the presence of a major amount of  $Cd_5Sb_4$  and minor amounts of both Sb and CdSb. The previous reactions explained in sample  $5_f$  can be assumed here, too. The remaining Sb represents the amount of the original pure component which cannot take part in the reactions due to its high percentage in this part of the phase diagram of the system.

### 4. Discussion and Conclusions

It was found that the concentration of Cd is rather higher in quenched samples than in the furnace-cooled ones. Sample  $2_q$  shows an exceptionally high concentration of Cd and was found to be composed of Cd with trace amounts of both  $Cd_4Sb_3$  and CdSb phases. The Sb phase was found in quenched and furnace cooled samples and its percentage was nearly the same in both samples of the same concentration. CdSb phase was found in all samples except that of 7 at% Sb; while  $Cd_4Sb_3$  is present in almost equal amounts in both quenched and furnace-cooled samples of 20 and 37 at% Sb, it disappeared completely in other samples and it reappeared only in sample  $7_q$ . It should be mentioned that the presence of  $Cd_4Sb_3$  in the samples studied in the present work agrees well with the work done by other workers [4, 6, 7]. Moreover, the



Fig. 14. X-ray diffraction patterns of furnace-cooled samples: a)  $3_f$  before and after heat treatment, b)  $5_f$  before and after heat treatment, c)  $7_f$  before and after heat treatment

X-ray diffraction analysis of the samples showed that there is an unknown phase in samples of low Sb content, i.e. samples  $l_f$  and  $2_f$ . The diffraction lines of this phase were not belonging to that of all known phases of the Cd–Sb system and not recorded previously in the ASTM cards, i.e., this phase was not identified before. This phase was given the formula  $Cd_5Sb_4$  and the analysis showed that it is belonging to the orthorhombic system. The analysis of the heat-treated samples had shown that  $Cd_5Sb_4$  is produced by heat treating of all samples, whatever their corresponding original composition. This fact indicates that the  $Cd_5Sb_4$  phase is a high-temperature phase which can exist at normal temperature as a metastable phase.

From the present results, the investigation of the surface structure of the samples by a metallurgical microscope showed the presence of the different phases which were previously identified by X-ray and electron diffraction analyses. Moreover from the relations of stability ranges of different phases and composition of the alloys, the approximate composition of any alloy of Sb content from 7 to 70 at% prepared under similar conditions followed in the present work can be found.

Besides, the present results agree with the work done by Psarev and Kostur [7] since it was found that the behaviour of the phase diagram is due to the independent crystallization of CdSb and Cd<sub>4</sub>Sb<sub>3</sub> as well as structural and phase transitions which may take place in these alloys. The phase transitions were observed also after the given samples were subjected to a heat treatment, which agrees with the work of Psarev and Kostur [7]. However, the phase  $Cd_5Sb_4$  was not identified by these workers [7], which may be due to the difference in the preparation temperature of the alloys. Meanwhile, the  $Cd_8Sb_2$  phase was given in the phase diagram published by Hansen [12] as well as in the work of Psarev and Kostur [7]; but this phase was not completely identified in the present work. This may be due to that this phase is a metastable phase and disappeared by subsequent transformation to a stable phase. CdSb was found to be the only stable phase in the phase diagram of Hansen [12], while its homogeneity range was found in the present work to be at 50 to 50.5 at% Sb as compared with 47 to 50.5 at% Sb shown in the diagram of Murakami and Shinagawa [14].

Consequently, one can conclude that the contradictions in the phase diagram of the Cd-Sb system is based on the fact that the individual crystallization of Cd-Sb alloys is dependent on several factors such, as superheating temperature over the liquidus line, rate of heating and that of cooling, heat treatment regimes applied, and eventually on composition of the given alloy. However, these contradictions in the phase diagram of all alloys are not always to find as has been published by Abou-Saif et al. [15] during their work on the structure of Al-Sn alloys.

## References

- I. Y. NEMISH, V. K. MALYUTENKO, and L. N. ZARUBIN, Poluprov. Tekh. Mikroelectron 7, 66 (1972).
- [2] YA. A. UGAI, T. A. MARSHAKOVA, N. A. IGNATEV, K. B. ALEINIKOVA, and N. S. DANILOHENKO, Protsessy Rosta Krist., Plenok Poluprov., 1970 (p. 404).
- [3] YA. A. UGAI and T. A. MARSHAKOVA, Protsessy Sin. Rosta Krist., Plenok Poluprov., Mater. Simp., 1965 (p. 122).
- [4] K. A. DOBRYDEN and V. I. PSAREV, Zh. fiz. Khim. 40, 2894 (1966).
- [5] M. K. MAKHOVA, D. P. BELOTSKII, and M. P. KOTSYMAKHA, Izv. Akad. Nauk SSSR, Ser. neorg. Mater. 14, 204 (1978).
- [6] E. I. YAREMBASH, M. D. KORSAK, and A. A. ELESEEV, Izv. Akad. Nauk SSSR, Ser. neorg. Mater. 6, 732 (1970).
- [7] V. I. PSAREV and T. A. KOSTUR, Izv. Akad. Nauk SSSR, Ser. neorg. Mater. 13, 2140 (1977).
- [8] K. A. DOBRYDEN, Izv. Akad. Nauk SSSR, Ser. neorg. Mater. 8, 1563 (1972).
- [9] N. L. KOSTUR and V. I. PSAREV, Simp. Protsessy Sin. Rosta Krist., Plenok Poluprov., Mater. Tezesy Dokl., Novosibirsk 1965 (p. 13).
- [10] I. M. BARENKO, R. A. PAVLOV, A. F. SEMIZOROV, and Z. V. PANKEVICH, Protsessy Sin. Rosta Krist., Plenok Poluprov., Mater. Simp. 1965 (p. 1967).
- [11] KH. M. KURBANOV and S. H. MAVLONOV, Dokl. Akad. Nauk Tadzh SSR 11, 16 (1968).
- [12] M. HANSEN, Constitution of Binary Alloys, McGraw-Hill Publ. Co., 1958.
- [13] L. W. AZARDFF, Elements of X-Ray Crystallography, McGraw-Hill, Publ. Co., 1968.
- [14] T. MURAKAMI and T. SHINAGAWA, Kinzoku-No-Kenkyu 5, 283 (1928).
- [15] E. A. ABOU-SAIF, M. ABD-RABO, M. M. EZZO, A. A. GAMIL, and A. A. MOHAMED, phys. stat. sol. (a) 67, K101 (1981).

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