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Superconductivity of a New Metastable Phase of Scandium–Chromium

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Although traces of superconductivity in the scandium–chromium system were found quite some time ago (*1*), it was not until just recently that we were actually able to stabilize a superconducting binary alloy by adding small amounts of boron to the arc-melt. A sharp transition ($T_c = 6.4°K$) with a full throw and a substantial specific heat anomaly was observed in an arc-melted sample of the composition $Sc_{0.75}Cr_{0.1875}B_{0.0629}$. This appeared to be the optimal composition since other compositions resulted in a degradation of the superconductivity. Additions of small percentages of other elements such as C, N, and Si were unsuccessful in stabilizing the superconducting phase. The samples were carefully scanned with the electron scanning microscope, but no superconducting elements or compounds could be detected.

The amount of the superconducting phase was reduced considerably by annealing the arc-melts at 500°C and disappeared totally when annealed at 650°C. Since the superconducting phase was destroyed by pulverizing the samples, Gandolfi photographs of small arc-melted balls were made in order to identify the phase.

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The X-ray pattern of the superconducting arc-melt $Sc_{0.75}Cr_{0.1875}B_{0.0629}$ showed the presence of free Sc, some Cr- and ScB_2 and a number of unidentified reflections, as shown in Table I. The X-ray pattern of the same sample annealed at 500°C showed a considerable decrease of intensity for the unidentified lines. At the same time, weak lines of Cr showed up. The lines disappeared after annealing at 650°C and rather strong lines of free Cr were then observed. Also the Sc reflection ($d = 2.64$), which does not overlap with lines of the new phase, shows a considerable increase in intensity after annealing, indicating an increase in Sc concentration due to decomposition of the new Sc–Cr phase. Since the amount of the superconducting phase showed the same trend, we concluded that the unidentified lines must be attributed to the superconducting phase, which starts to decompose into free Sc and Cr at 500°C. From the X rays it is estimated that the sample $Sc_{0.75}Cr_{0.1875}B_{0.0629}$ contains 15–20% of the new phase, which is in accordance with specific heat measurements. The unidentified lines could be indexed on a cubic lattice with $a = 12.33$ Å and space group $Fd3m$. This and the fact that the reflections 511 ($d = 2.36$) and 440 ($d = 2.18$) are relatively strong indicate that the phase has the $E9_3$-type structure (*2, 3*). Assuming that the lattice constant of the $E9_3$-phase is roughly proportional to the average radius of the metals in the compound,

TABLE I

LOW-ANGLE d VALUES AND INTENSITIES OF $Sc_{0.75}Cr_{0.1875}B_{0.0629}$[a]

d_{obs}	I_A	I_B	I_C		$I_{calc}(N)$	$d_{calc}(N)$	$h\,k\,l\,(N)$
2.84	m	mw	mw	Sc	5	2.83	3 3 1
2.64	w	m	m	Sc			
2.56	vw			CrB_2			
2.51	s	s	s	Sc	12	2.52	4 2 2
2.36	w	vw			5	2.37	5 1 1 / 3 3 3
2.28		vw	m	Cr			
2.18	mw	w			8	2.18	4 4 0
2.14	mw	w		ScB_2			
2.07	vw				4	2.08	5 3 1
2.04		w	ms	Cr			
1.94	m	m	m	Sc	5	1.945	6 2 0

[a] A, before annealing; B, after annealing at 500°C; C, after annealing at 650°C; N, new phase.

we estimate the composition of the new phase ($a = 12.33$ Å) to be $Sc_{2.15}Cr_{0.85}B_x$ (compare for instance with Ti_2Ni, $a = 11.278$ Å) (*4*). Low-angle intensities were calculated in a crude way by varying the positional parameters of $E9_3$-type Ti_2Ni (*2*). Since the scattering factors of Sc and Cr are so close, a statistical distribution was assumed (*3*). Table I shows that the strongest calculated intensities ($I > 4$) are indeed the ones which are observed, although many of them do overlap with the Sc lines. Reflections for which $I_{calc} < 4$ were not observed and therefore are not included in the table.

This metastable phase $Sc_{2.15}Cr_{0.85}B_x$ ($x < 0.01$) is one of several superconducting phases of the $E9_3$-type. Some superconducting phases have been incorrectly ascribed to the $E9_3$-type structure (*5*). Another new metastable cubic (Nb-Rh)C_x phase ($a = 11.89$ Å) with the same space group *Fd3m* was found to be superconducting at 10.3°K (*6*) and might be another example of a metastable superconducting $E9_3$-type phase.

The new $E9_3$-phase in the Sc–Cr–B system is quite different from the ones reported in the past. These were all low-temperature phases and unstable at higher temperatures, whereas the opposite is true in the Sc–Cr–B system. Since no $E9_3$-phase has ever been stabilized with boron before, the stability range of these phases may be different from those stabilized with C, N, or O. Furthermore, according to the literature, no compounds in the Sc–Cr system have ever been reported and the two elements are actually considered immiscible.

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