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PRESSURE DEPENDENCE OF THE MAGNETIC ORDERING TEMPERATURES IN Cr-Fe ALLOYS*

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ABSTRACT

The pressure dependences of the magnetic transition temperatures of Cr-2.5 and 2.8 at.% Fe single crystal alloys have been determined by electrical resistance and ultrasonic measurements. The results show that the 1 bar triple point (P,I,C) in the temperature concentration plane occurs at a concentration of ~ 2.5 at.% Fe in contrast to the previously published value of 4 at.% Fe. The high pressure data showed an abrupt change in the pressure dependence of the I-C transition at 3.3 kbar, from which it is speculated that an additional magnetic phase exists.

INTRODUCTION

It is well known that the Cr rich-transition metal alloys exhibit several different magnetic phases and that the transition temperatures between phases are very sensitive to hydrostatic pressure.[1,2] In these alloys three distinct magnetic phases have been observed: (1) paramagnetic (P), (2) incommensurate antiferromagnetic (I), and (3) commensurate antiferromagnetic (C). Among the various Cr-transition metal systems, the magnetic properties of the Cr-Fe alloy system are anomalous.[2,3] There is also some uncertainty in the magnetic phase diagram of this system, especially in the concentration range 2 to 4 at.% Fe.[4] Neutron diffraction measurements by Ishikawa et al[5] have indicated that in the 2 to 4 at.% Fe concentration range the ordering sequence at a pressure of 1 bar is P-I-C with decreasing temperature; however, Arrott et al[6] have suggested from their neutron diffraction results on a Cr-2.3 at.% Fe alloy that the appearance of the I-phase may be due to concentration inhomogeneities. Recently we have shown that well-defined phase transitions can be observed via electrical resistance and ultrasonic measurements on a pure, homogeneous single crystal alloy.[7] Specifically, on a Cr-2.8 at.% Fe sample, it was found that only one transition (P-C) occurred at a pressure of 1 bar and that the triple point among the P, I, and C phases exists in the positive pressure plane. The implication of these results is that the triple point among the P, I, and C phases in the temperature-concentration plane occurs at a concentration less than 2.8 at.% Fe.

The purpose of this work was to locate the P,I,C triple point in the temperature-concentration plane (at 1 bar) and to study the pressure dependences of the transitions. We report the results of electrical resistance and acoustic measurements on two single crystal alloys with concentrations of 2.5 and 2.8 at.% Fe. (The results presented here for 2.8 at.% Fe alloy are an extension to higher pressures of previous work.[7]) They show that the triple point in the temperature-concentration plane occurs very near 2.5 at.% Fe. The high pressure results have led to the speculation of the existence of a new magnetic phase, and it also appears that the I-C transition temperature may be driven to 0°K with easily accessible laboratory pressures (< 10 kbar).

EXPERIMENTAL RESULTS

The single crystals used in this study were grown by an arc-zone melting technique.[8] Both constituent elements contained less than 50 ppm of other transition metals and the compositions of the crystals were determined by atomic absorption spectroscopy to be 2.5 and 2.8 at.% Fe. The resistance and acoustic measurement techniques along with the high pressure helium gas vessel are described elsewhere.[7]

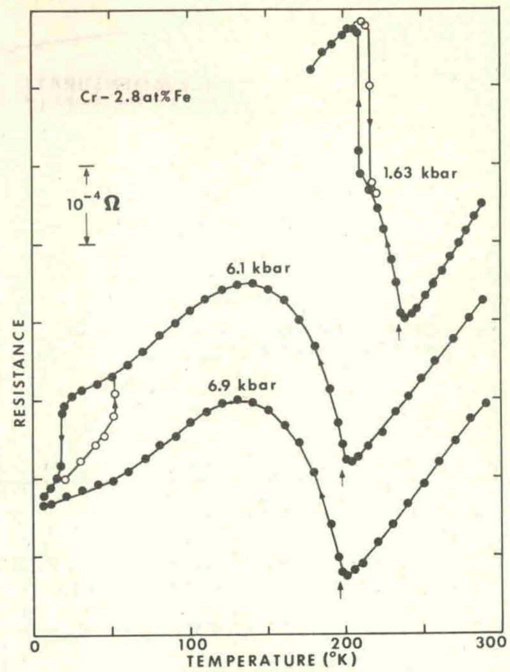

Fig. 1 Typical resistance isobars for the 2.8% alloy. The arrows indicate the location of the inflection points.

In Fig. 1 several typical resistance isobars are shown for the Cr-2.8 at.% Fe alloy. For the various isobars an inflection point is observed ~ 5°K below the resistance minimum. These inflection points correspond in temperature to a sharp "cusp" type of anomaly in the ultrasonic velocities and are interpreted as the P-I transitions.[7] For the 1.63 kbar isobar a second transition is observed, which is characterized by a discontinuous increase in resistance with decreasing temperature. This is the I-C transition and the hysteresis associated with this first order transition increases with increasing pressure. The magnitude of the discontinuous increase in resistance is found to decrease with increasing pressure and becomes very small over the pressure range 3 to 4 kbar. For pressures in excess of 4 kbar, the discontinuous increase in resistance is observed to change to a discontinuous decrease in resistance (cf. the 6.1 kbar isobar in Fig. 1). The magnitude of the discontinuous decrease in resistance increases with increasing pressure, which is opposite of the behavior observed for the lower pressure isobars. The possible significance of the change in the resistance discontinuity will be discussed in the next section. Finally, it is observed that the I-C transition temperature can be driven towards 0°K with the application of sufficient pressure (note that there is no I-C transition down to 4°K for the 6.9 kbar isobar in Fig. 1). Similar resistance anomalies are also observed for the Cr-2.5 at.% Fe alloy.

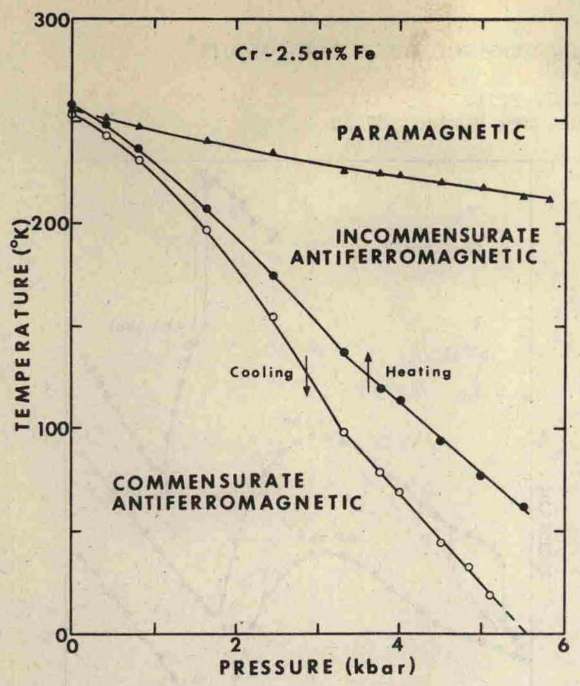

Fig. 2 The magnetic phase diagram for the 2.5% alloy. The arrows indicate the hysteresis.

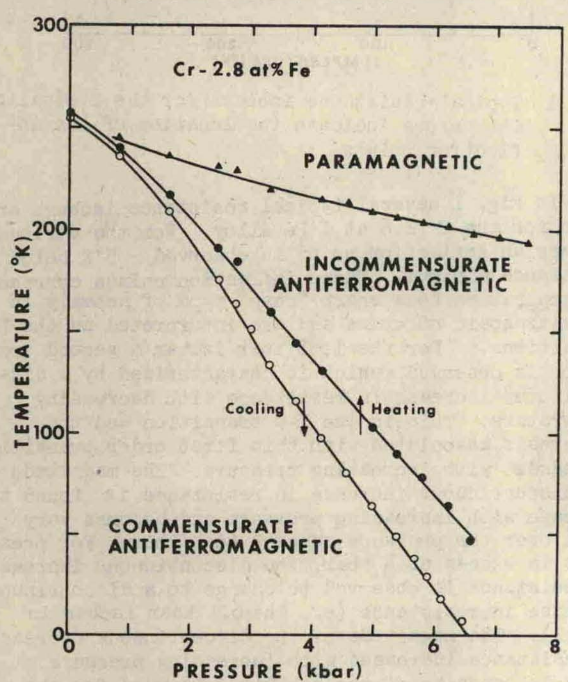

Fig. 3 The magnetic phase diagram for the 2.8% alloy. The arrows indicate the hysteresis.

The temperature-pressure magnetic phase diagrams for the 2.5 and 2.8 at.% Fe alloys are shown, respectively, in Figs. 2 and 3. Except for the low pressure region, the general features of the phase diagrams are similar for both alloys. The P-I transition temperature is observed to be relatively insensitive to pressure and to become progressively more insensitive to pressure with increasing pressure. In contrast, the I-C transition temperatures are very sensitive to pressure — decreasing quadratically with pressure up to ~ 3.3 kbar. At 3.3 kbar an abrupt change to a linear dependence is observed.

DISCUSSION

The various features of the phase diagrams (Figs. 2 and 3) will be discussed in order of increasing pressure. At low pressures for the 2.8% alloy, it has been previously shown[7] that only the P-C transition occurs at 1 bar and that the triple point (P,I,C) occurs at ~ 0.5 kbar. (There are actually two triple points because of the hysteresis associated with the I-C transition.) The current results, for the 2.5% alloy at 1 bar, show that with decreasing temperature there are two transitions (P-I and I-C) which are separated by only 2K°. On the other hand, with increasing temperature only one transition (C-P) is observed and the triple point (P,I,C) occurs in the positive pressure plane at ~0.25 kbar. The results for the cooling cycle show that the P-I and I-C boundaries extrapolate to an intersection point in the negative pressure plane (~.25 kbar). It is concluded from these observations that the triple point (P,I,C) at 1 bar in the temperature-concentration plane occurs at an Fe concentration very close to 2.5%. It should be noted that there will be two triple points in the temperature-concentration plane because of hysteresis effects.

In the intermediate pressure range an abrupt change in the pressure dependence of the I-C transition temperature is observed for both alloys. This change from a quadratic to a linear pressure dependence occurs at ~ 3.3 kbar and is independent of concentration and the direction of the temperature cycle. The temperature at which this change occurs, however, is dependent on concentration and the sense of the temperature cycle. The slope $(\partial T/\partial P)$ at 3.3 kbar was observed to change from 71°K/kbar to 44°K/kbar for the 2.5% alloy, and for the 2.8% alloy the slope change was 53°K/kbar to 41°K/kbar. In addition to the change in the functional pressure dependence of the I-C transition temperature at 3.3 kbar, the character of the resistance anomaly associated with this transition changes (cf. Fig. 1). These results seem to suggest the presence of an additional magnetic phase. A search was made by the present measuring techniques for a new phase boundary, and the results were null. Another technique, such as neutron diffraction measurements under pressure, will be necessary to establish the possible existence of a new magnetic phase.

In the high pressure limit the I-C transition temperature is observed to approach absolute zero linearly with pressure. For the cooling cycle data the I-C phase boundary extrapolates to 0°K at critical pressures of 5.5 and 6.5 kbar, respectively, for the 2.5 and 2.8% alloys. In fact at a pressure of 6.7 kbar there was no evidence of the I-C transition down to 4°K for the 2.8% alloy (cf. Fig. 1). This appears to be the first observation where the I-C transition temperature of a Cr alloy has been followed to liquid helium temperatures as a function of pressure.

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