Cause of low-temperature resistance maximum in titanium alloys

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It was shown earlier[1] that the resistivity of Ti_x-V_{1-x} alloys have anomalies that distinguish them from simple metallic systems.

In the temperature region 20–300 °K, depending on the concentration, three types of dependences of the resistivity $\rho(T)$ can be observed, with positive ($0 < x < 0.60$), zero ($x = 0.60$), and negative ($0.60 < x < 0.85$) temperature coefficients of resistivity (TCR).

On the other hand, at temperatures $\lesssim 15$ °K, i.e., in the region of the residual resistivity, a decrease of the resistivity is observed, extending over several degrees and ending with a transition to the superconducting state.

As a result, for the first two types of $\rho(T)$ plots, the resistive transitions to the superconducting state turn out to be strongly stretched out, and maxima appear on the curves with the negative TCR.

The models[1] and[2] proposed to explain these anomalies were based on the common assumption that the decrease of the resistance and correspondingly the maximum of the resistance are due to superconductivity.

It became clear later on that this phenomenon can also be regarded as a property of the normal state, without resorting to the superconductivity mechanism.

This possibility stems from the fact that in the entire concentration range ($0 < x < 0185$) and not only ($0.60 < x < 0.85$), where there is a negative TCR, one can assume that an additional contribution is made to the resistivity by scattering with spin flip, which is characteristic of Kondo alloys.

It is known that the functional dependence of this contribution on the temperature can be different. The model of localized spin fluctuations[3] predicts a curve with saturation at $T = 0$ °K, whereas the Abrikosov model[4] predicts a curve with a maximum at intermediate temperatures.

It is precisely the latter case which is an alternative to the models of[1] and[2], since all the singularities of the resistivity which are characteristic of the Ti_x-V_{1-x} alloys are accounted for if the "Kondo" maximum lies somewhat higher than the temperature of the superconducting transition.

This possibility of treating the considered phenomena was pointed out to us by L. P. Gor'kov.

The question of the cause of the anomalous decrease of the resistance can be answered experimentally by using the influence of a longitudinal magnetic field. If the effect is due to superconductivity, then the resistance should increase with increasing magnetic field and should reach the value of the residual resistivity. To the contrary, if the effect itself is due to the "Kondo" mechanism, then the resistivity can either decrease under the influence of the magnetic field, or else be independent of the field, in view of the small mean free path of the electrons.

If the external magnetic fields greatly exceed the critical superconductivity fields $H_{c2}(T)$, and are sufficient for a complete suppression of all symptoms of superconductivity, then we can hope to determine the course of $\rho(T)$ of the normal state at $T \ll T_c$. By the same token, we can qualitatively determine the type of the functional dependence of the "Kondo" contribution to the resistance.

We present here the main results of our investigations of the effect of a magnetic field on the resistivity of Ti_x-V_{1-x} alloys.

Figure 1 shows the effect of a 140-kOe magnetic field on the three types of $\rho(T)$ relations described above.

We see that the action of the magnetic field is typical of the superconducting state both below and above the critical temperature. In this sense, the case with negative TCR is likewise no exception.

We can thus state that the low-temperature maximum of the resistance in titanium alloys is of superconducting origin and is the result of the fact that the traces of superconductivity are preserved up to temperatures exceeding the temperature of the maximum. In this case they can be traced all the way to 13–14 °K, whereas

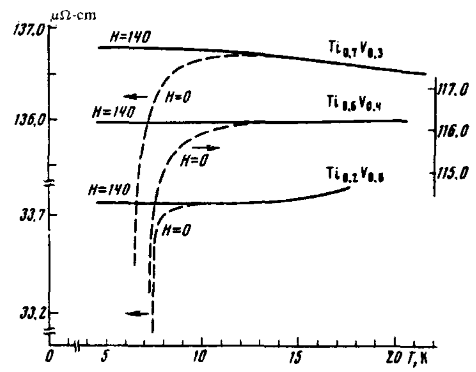

FIG. 1. Influence of longitudinal 140-kOe magnetic field on the temperature dependence of the resistivity for three alloys of the Ti_x-V_{1-x} system.

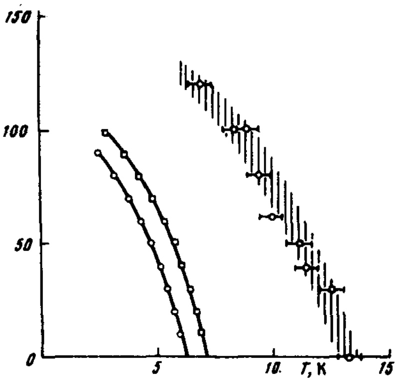

FIG. 2. (H_c–T_c) diagrams for the alloys $Ti_{0.6}$–$V_{0.4}$ (□) and $Ti_{0.7}$–$V_{0.3}$ (○).

the critical temperatures of Ti–V alloys determined from the jumplike change in the resistance do not exceed 8 °K.

Our data allow us to describe fully this "high-temperature" superconductivity. We have attempted to determine its critical parameters and to plot the (H_c–T_c) phase diagrams.

Figure 2 shows the results of such a construction for the alloys $Ti_{0.70}$–$V_{0.30}$ and $Ti_{0.60}$–$V_{0.40}$. The solid lines show the phase curves determined from the jumplike change of the resistance.

The shaded strip denotes the limit to which traces of superconductivity could still be traced. For various reasons, it cannot be established more accurately, and is the same for the two samples.

Insofar as we know, this is the first time that a double phase diagram and an upper phase curve were established, particularly for the Ti–V alloy system.

This raises the question of realizing full superconductivity with a higher critical temperature.

In this respect, the mechanism of fluctuating pairing of the conduction electrons, used in[2] to explain the broad resistive transition, leaves nothing to hope for.

To the contrary, the model of[1] regards wide transitions as the result of a partial suppression of the real superconductivity by the spin inhomogeneities, and determines the critical temperature T_c^{bs} (bs stands for band structure) that is potentially possible for the structure of a given alloy from the start of the transition *from the normal to the superconducting state.*[5]

Therefore superconductivity with critical parameters corresponding to the shaded phase curve on Fig. 2 can be realized in the Ti–V system if we can "remove" the source of the spin inhomogeneities.

As to the question of the character of the temperature dependence of the "Kondo" contribution to the resistivity, one can assume on the basis of the form of the $\rho(T)$ curve with negative TCR at $T < T_c$ in a 140-kOe field (Fig. 1) that it is described by a curve with saturation. This behavior agrees qualitatively with the model of localized spin fluctuations,[3] which was used in[1] to explain the negative TCR.

In conclusion, we call attention to a circumstance that we consider important. The low-temperature resistivity maximum is a phenomenon quite frequently observed. It is usually attributed, however, to some ordering, most frequently magnetic.

As shown in this article, superconductivity can also be responsible for this effect. It is possible that it was due to superconductivity also in a number of other cases.

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