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## SUPERCONDUCTING PROPERTIES OF $K_3C_{60}$ AND $Rb_3C_{60}$ SINGLE CRYSTALS IN HIGH FIELDS.

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**Abstract** The critical superconducting temperature of  $Rb_3C_{60}$  and  $K_3C_{60}$  single crystals was measured in static magnetic fields up to 23 T by a resistive method. It is shown that within the experimental accuracy no enhancement of the critical field  $H_{C2}$  is found at low temperature. The  $H_{C2}(T)$  follows the Werthamer, Helfand and Hohenberg theory quite well.

### INTRODUCTION

Some recent measurements performed on  $K_3C_{60}$  compounds in powders<sup>1</sup> seem to show an enhancement of the critical field  $H_{C2}$  above the values predicted by the Werthamer, Helfand and Hohenberg (WHH) theory<sup>2</sup>. The knowledge of the  $H_{C2}(T)$  curve may give important information for the understanding of the pairing process in these materials. We present here first results obtained on  $K_3C_{60}$  and  $Rb_3C_{60}$  single crystals.

### SAMPLE PREPARATION

The preparation of the compounds has been described in details elsewhere<sup>3</sup> and will be only briefly given here. Single crystals of  $C_{60}$  are synthesized starting from pure  $C_{60}$  powder at about 450°C using a vapor transport method. The fcc crystal structure and lattice constant were confirmed by X-rays experiment. The samples were mounted with electrical contacts and sealed together with fresh potassium in a Pyrex glass apparatus. Uniform doping was accomplished using a repetitive dope-anneal process until the

resistance of the sample reached a minimum. For the case of  $K_3C_{60}$  the room temperature resistivity ratio is typically 2, indicating a metallic behavior<sup>3</sup>.

### EXPERIMENTAL

The sample cell was filled with helium gas to ensure good thermal contact at low temperature. A 100 ohm Allen-Bradley resistor was glued against the Pyrex cell at the sample position. The resistance measurements were made by raising the temperature in a constant magnetic field from 4 to 5 K up to about 30 K at a maximum rate of .5 K/mn. No difference was observed between the magnetoresistance curves obtained by slowly sweeping the temperature or stabilizing it. This shows that there was no detectable temperature gradient between the sample and the thermometer.

The magnetoresistance of the samples was measured using a four probe method with an ac effective current of 100  $\mu$ A. We have checked that no current effect on  $T_c$  was present up to 100  $\mu$ A. The thermometer calibration was carefully undertaken as a function of the field up to 23 tesla.

The static field was produced by resistive coils (23 T,  $K_3C_{60}$  samples) and a superconducting 17 T magnet ( $Rb_3C_{60}$ ).

### RESULTS

We have measured two potassium compounds of nominal chemical formula  $K_3C_{60}$ . The transition width at  $T_c$  ranges from .5 K at  $B = 0$  up to 2.4 K at  $B = 23$  T for the first one and from .5 K to 1.2 K for the second one. For the  $Rb_3C_{60}$  compound the values are .4 K ( $B = 0$ ) and 3.2 K ( $B = 17$  T). On figure (1) two transition curves are displayed at  $B = 0$  and  $B = 23$  T for the most homogeneous  $K_3C_{60}$  compound ( $n^{\circ}2$ ). The value of  $T_c$  is chosen at the midpoint of the transition width  $\Delta T$ .

On figures (2) and (3) we have reported the  $H_{C2}$  (T) curves for the two  $K_3C_{60}$  compounds and the  $Rb_3C_{60}$  compound respectively. The continuous lines are obtained with the WHH theory<sup>2</sup> assuming no spin-orbit and no paramagnetic effects. It can be seen that at least for the  $K_3C_{60}$  compounds a quite good agreement between theory and experiment is obtained, within experimental accuracy. For the case of  $Rb_3C_{60}$  the restricted range of magnetic field (0-17 T) does not allow a clear conclusion.

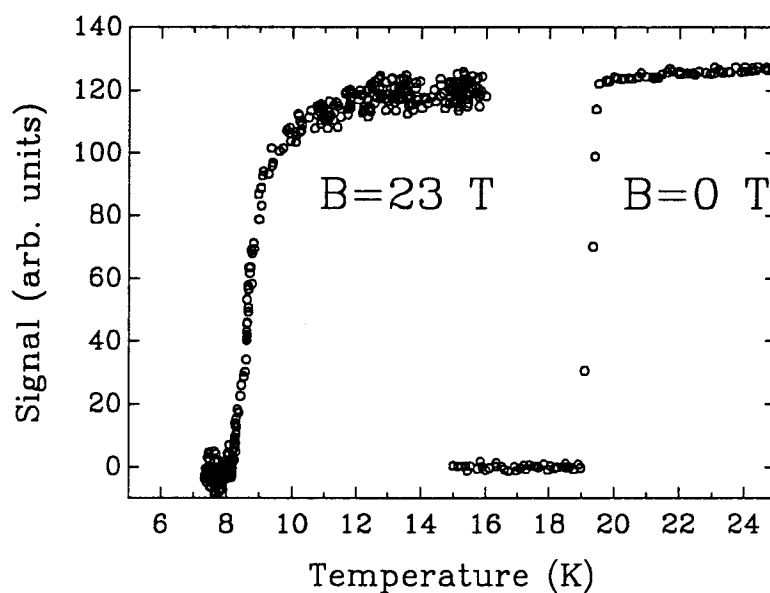


FIGURE 1 Resistive transitions for the  $K_3C_{60}$  compound n° 2 at 0 and 23 T respectively.

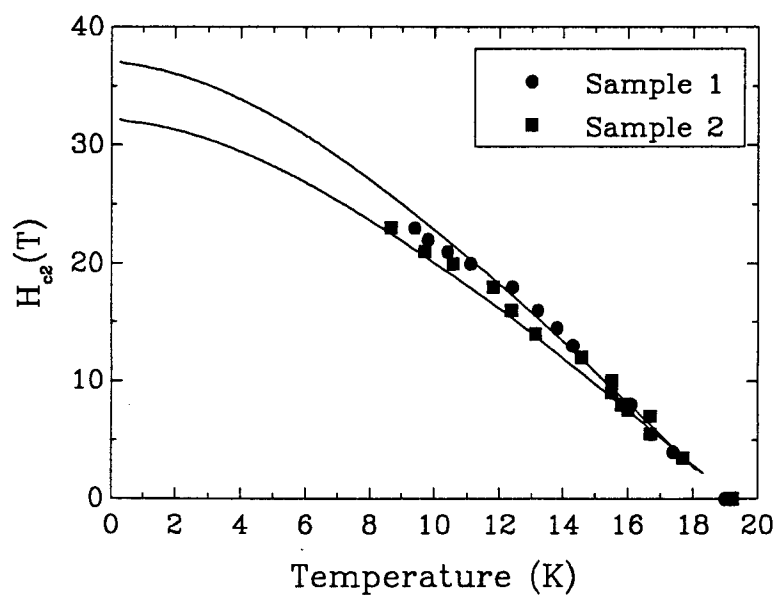


FIGURE 2 Higher critical field  $H_{c2}$  as a function of temperature for  $K_3C_{60}$  compounds n°1 (full squares) and n°2 (full circles). Continuous lines are WHH fits adjusted with the initial slope at  $T_c$ .

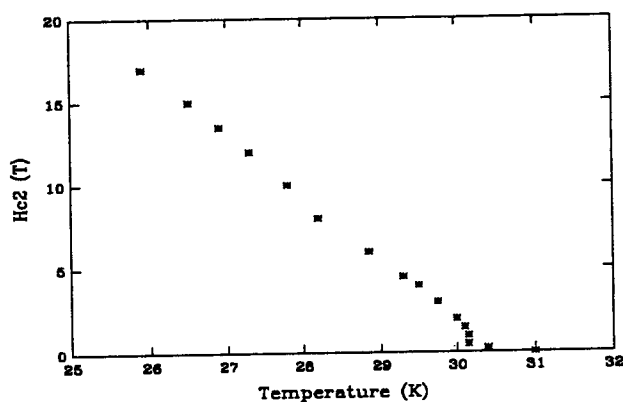


FIGURE 3 Higher critical field  $H_{C2}$  as a function of temperature for  $Rb_3C_{60}$

TABLE 1 Main superconductivity parameters of the potassium and rubidium doped fullerenes.

Parameters	$K_3C_{60}$ n°1	$K_3C_{60}$ n°2	$Rb_3C_{60}$
$T_c$ (0) (K)	18.9	19.2	31
$H_{C_2}$ (0) (T)	37.8	30.1±1	61
$\ell$ (Å)	27±7		
$\xi$ (0) (Å)	29	32.5	22.8
$\xi_0$ (Å)	131		
$\sqrt{\ell\xi_0}$ (Å)	59		
$\left(\frac{\partial H_{C_2}}{\partial T}\right)_{T=T_c}$ (T/K)	-2.9	-2.27	-2.85

On table (1) we have gathered the main parameters of the superconductivity for these compounds.  $H_{C_2}(0)$  is the extrapolated value given by the WHH theory :  $H_{C_2}(0) = 0.69 \cdot \left(\frac{\partial H_{C_2}}{\partial T}\right)_{T_c} \cdot T_c$ . The Ginzburg-Landau coherence length  $\xi(0)$ , in the clean limit, is obtained with the formula :  $H_{C_2}(0) = \frac{\Phi_0}{2\pi\xi(0)^2}$  where  $\Phi_0$  is the flux quantum. The BCS length is given by  $\xi_0 = \frac{0.18\hbar v_F}{k_B T_c}$ , where  $v_F$ , the Fermi velocity can be estimated  $5 \cdot 10^6$  cm./s<sup>4</sup>. From the resistivity ratio the electronic mean free path

$\ell$  can be deduced <sup>4</sup> and also the coherence length in the dirty limit :  $\xi = \sqrt{\ell\xi_0}$ . We see from this data that  $K_3C_{60}$  is neither in the clean nor in the dirty limit.

### CONCLUSION

We have measured the critical field of single crystals of  $Rb_3C_{60}$  and  $K_3C_{60}$  compounds using a resistive method up to 23 T. Within experimental accuracy a good agreement with the WHH theory is found. This indicates that these compounds have conventional BCS superconducting properties as was already found on powdered samples <sup>5-6</sup>. Since the compounds are not in the clean limit ( $\ell \gg \xi_0$ ) the observation of the Fulde-Ferrell state <sup>7</sup> seems to be most improbable.

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