

## Alkali-metal isotope effect in $\text{Rb}_3\text{C}_{60}$

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The rubidium isotope effect has been measured in superconducting crystals of  $\text{Rb}_3\text{C}_{60}$ . With  $T_c \propto M^{-\alpha}$ , we find  $\alpha_{\text{Rb}} = -0.028 \pm 0.036$ . This result puts constraints on the superconducting mechanism in  $\text{Rb}_3\text{C}_{60}$ .

### 1. EXPERIMENTS AND RESULTS

Single crystals of  $\text{C}_{60}$  (produced from  $^{12}\text{C}$ ) were intercalated with rubidium following a standard procedure [1]. Samples were intercalated with either natural abundance rubidium  $^{\text{na}}\text{Rb}$  (72.2%  $^{85}\text{Rb}$ , 27.8%  $^{87}\text{Rb}$ ), isotopically enriched  $^{87}\text{Rb}$  (0.8%  $^{85}\text{Rb}$ , 99.2%  $^{87}\text{Rb}$ ), or isotopically enriched  $^{85}\text{Rb}$  (99.8%  $^{85}\text{Rb}$ , 0.2%  $^{87}\text{Rb}$ ). All rubidium used was first extracted from  $\text{RbCl}$  using a calcium reduction technique. The superconducting transition temperature  $T_c$  for the samples was determined using dc 4-probe resistivity measurements.  $T_c$  was defined as the peak in the temperature derivative of the resistance,  $dR/dT$ ; this was reproducible to within 5mK for a given sample. The actual transition width (defined as the separation between the maximum and minimum in the second derivative) was between 140mK and 180mK for all samples.

Fig. 1 shows  $dR/dT$  for  $^{\text{na}}\text{Rb}$ ,  $^{87}\text{Rb}$ , and  $^{85}\text{Rb}$  samples. The solid lines are cubic spline fits to the data. The maximum of the fit determines  $T_c$  (parabolic and gaussian fits yield essentially equivalent results). We find  $T_c (^{\text{na}}\text{Rb}) = 30.822$  K,  $T_c (^{87}\text{Rb}) = 30.836$  K, and  $T_c (^{85}\text{Rb}) = 30.816$  K.

### 2. ANALYSIS

In Fig. 2 we plot  $T_c$  versus average rubidium mass. Within experimental error, there is no rubidium isotope effect on  $T_c$  in  $\text{Rb}_3\text{C}_{60}$ . The solid curve is a fit to  $T_c \propto M^{-\alpha}$ , with  $\alpha = -0.028$ .

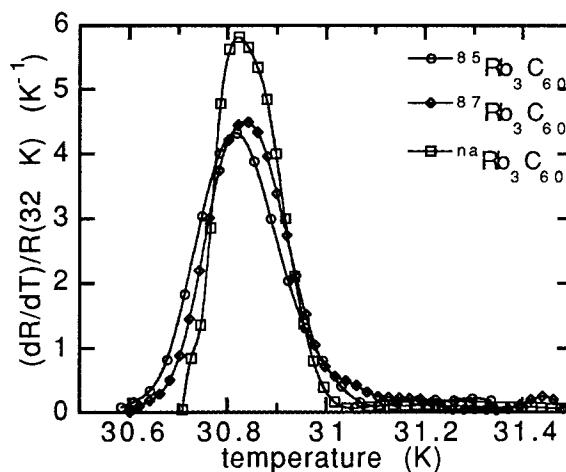


Figure 1. Derivative with respect to temperature of normalized resistance near  $T_c$  for  $^{85}\text{Rb}_3\text{C}_{60}$ ,  $^{87}\text{Rb}_3\text{C}_{60}$  and  $^{\text{na}}\text{Rb}_3\text{C}_{60}$ . Curves are cubic spline fits to the data. Position of curve fit maximum determines  $T_c$ .

For comparison, in Fig. 2 we show (dashed line) the result for the BCS maximum value of  $\alpha_{\text{Rb}} = 0.5$  normalized to the  $^{87}\text{Rb}_3\text{C}_{60}$  data point. Our final result is  $\alpha_{\text{Rb}} = -0.028 \pm 0.036$ . This value is consistent with the finding of Ebbesen et al. [2] that  $\alpha_{\text{Rb}} < 0.2$ . However, the improved error bars in our experiment place stringent limits on the possible contributions of alkali-optic phonons to the superconductivity.

A model of superconductivity in  $\text{Rb}_3\text{C}_{60}$  incorporating both on-ball carbon phonons and Rb-

$C_{60}$  optic modes would predict a direct rubidium isotope effect due to isotopic shift in phonon frequency. Our experiment places limits on the relative contributions of rubidium modes within such a model. Using as an upper bound  $\alpha_{Rb} < 0.044$  (two standard deviations above the measured value), detailed calculations [3] yield for the fractional contribution to the electron-phonon coupling constant  $\lambda_{Rb}/\lambda \leq \sim 0.3$ , with the ratio decreasing with increasing alkali mode frequency. Although the contribution of the alkali modes to  $T_c$  is at best small, the contribution of a low frequency alkali mode to  $\lambda$  can be substantial.

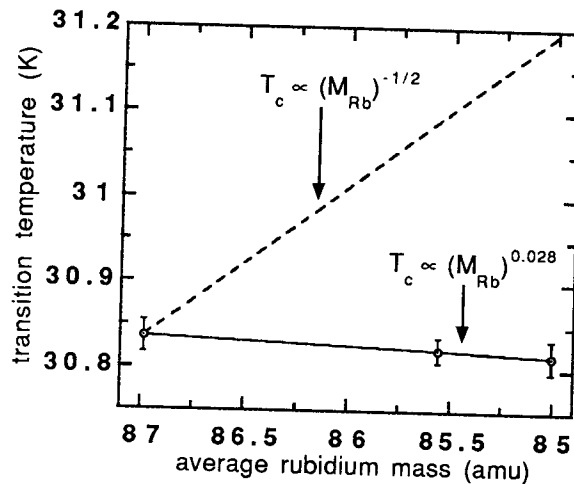


Figure 2. Plot of  $T_c$  versus average rubidium mass in  $Rb_3C_{60}$ . Solid line is fit of the data to  $T_c \propto M_{Rb}^{0.028}$ . Dashed line shows  $T_c \propto M_{Rb}^{-0.5}$  with proportionality constant chosen so that the line passes through the  $^{87}Rb_3C_{60}$  data point.

## ACKNOWLEDGEMENTS

This work was supported by NSF grants DMR-9017254 and DMR-9120269 and the Department of Energy under contract DE-AC03-76SF00098.

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3. B. Burk, V. H. Crespi, A. Zettl, and M. L. Cohen, (submitted to *Phys. Rev. Lett.*).