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Alkali-metal isotope effect in Rb_3C_{60}

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The rubidium isotope effect has been measured in superconducting crystals of Rb_3C_{60} . With $T_c \propto M^{-\alpha}$, we find α_{Rb}= -0.028 ± 0.036. This result puts constraints on the superconducting mechanism in Rb_3C_{60} .

1. EXPERIMENTS AND RESULTS

Single crystals of C_{60} (produced from ^{12}C) were intercalated with rubidium following a standard procedure [1]. Samples were intercalated with either natural abundance rubidium ^{na}Rb (72.2% ^{85}Rb, 27.8% ^{87}Rb), isotopically enriched ^{87}Rb (0.8% ^{85}Rb, 99.2% ^{87}Rb), or isotopically enriched ^{85}Rb (99.8% ^{85}Rb, 0.2% ^{87}Rb). All rubidium used was first extracted from 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 ^{na}Rb, ^{87}Rb, and ^{85}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 (^{na}Rb) = 30.822 K, T_c (^{87}Rb) = 30.836 K, and T_c (^{85}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 Rb_3C_{60}. The solid curve is a fit to $T_c \propto M^{-\alpha}$, with α = -0.028.

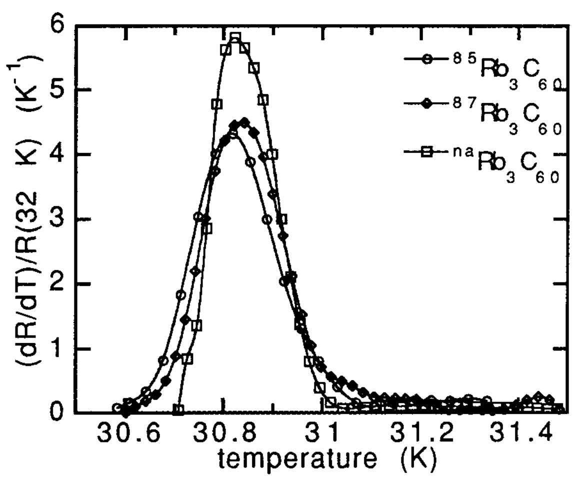

Figure 1. Derivative with respect to temperature of normalized resistance near T_c for $^{85}Rb_3C_{60}$, $^{87}Rb_3C_{60}$ and $^{na}Rb_3C_{60}$. Curves are cubic spline fits to the data. Position of curve fit maximum determines T_c.

For comparison, in Fig. 2 we show (dashed line) the result for the BCS maximum value of α_{Rb} = 0.5 normalized to the $^{87}Rb_3C_{60}$ data point. Our final result is α_{Rb} = -0.028 ± 0.036. This value is consistent with the finding of Ebbesen et al. [2] that α_{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 Rb_3C_{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 akali 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 λ can be substantial.

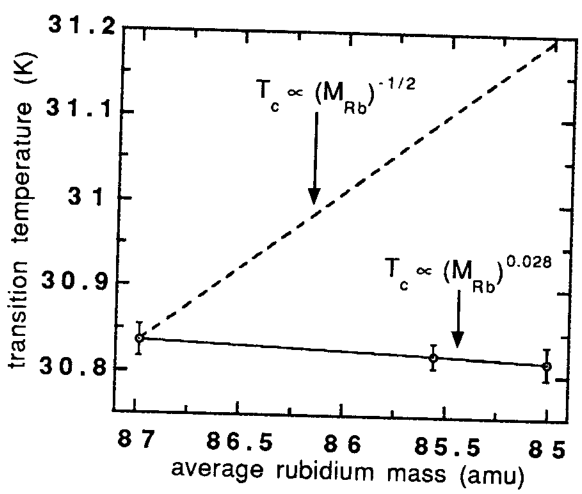

Figure 2. Plot of T_c versus average rubidium mass in Rb_3C_{60}. Solid line is fit of the data to $T_c \propto M_{Rb}^{0.028}$. Dashed line shows $T_c \propto M_{Rb}^{-0.5}$ with proportionality constant chosen so that the line passes through the $^{87}Rb_3C_{60}$ data point.

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