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Incommensurate Fluctuations in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$

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Abstract

A special neutron scattering technique has been used to discover an incommensurate fluctuation in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ that appears below T_c . The fluctuation is identified as a dynamic charge density wave since its scattering intensity appears to increase with increasing momentum transfer. The fluctuation is found at a wavevector near $2k_F$ and could be associated with a dynamic stripe phase.

MASTER

There is now growing evidence that charge-stripe order is found in high- T_c materials that are not optimally doped.¹ So far, incommensurate structure that supports the idea of charge-stripe order has been based on the observation of elastic scattering. Since no such elastic scattering has been observed in the materials with the highest transition temperatures it is obvious that investigations should proceed in search of inelastic, incommensurate structure that would represent dynamic charge or spin-ordering. It is obviously easier to identify static incommensurate structure than dynamic structure. However, special techniques have been developed that make such a search easier in the case of lower-dimensional materials.

A novel neutron scattering technique was used to identify a charge fluctuation in $\text{YBa}_2\text{Cu}_3\text{O}_{6.95}$ (YBCO) that had a wave vector equal to $2k_F$ for the chains.² The shape of the scattering showed that the fluctuation was 1D in nature and the wavevector was nearly equal to the wavevector of a charge density wave determined for the chains by scanning tunneling microscopy.³ The measurement technique is shown in Fig. 1 and relies on an integration along a given direction in momentum space. Scattering from 1D objects occurs in planes in reciprocal space, while scattering from a 2D object results in a line of scattering. Thus, lower dimensional scattering can be greatly enhanced when the measurement is set up so that the final wave vector k_f is perpendicular to the scanning direction as shown in Fig 1. The method would not work in the high- T_c materials without

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a way of excluding elastic scattering as the complexity of these materials and their impurity phases would result in a series of elastic peaks that would overwhelm the inelastic scattering. This is accomplished in the present measurement by a graphite filter that reduces the elastic scattering by about five orders of magnitude, but passes the inelastic events with a much higher efficiency.

It was decided that it would be productive to make this type of measurement on $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ since this material has no chains and any observed incommensurate scattering would have to stem from the planes in the material. It is difficult to obtain large crystals of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$, but polycrystalline rods that have either the a- or b-axis reasonably well oriented along the rod can be grown by the floating zone technique. Since the material is orthorhombic that means the (Π, Π) direction in square lattice notation is fairly well determined, but other directions are not. The sample used in the present measurements is the same one used to determine phonon lifetimes in an earlier set of experiments and is described in Reference 4. The T_c showed an onset at 84K and the transition was rather broad; extending to 75K. The sample composition is near optimum doping with the possibility of being somewhat over-doped. $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ has a superlattice structure in the Bi-O plane that yields elastic scattering peaks with a wave vector of about 0.21 along the (Π, Π) direction. This structure was easily identified and indeed is about 1000 times more intense than the inelastic, incommensurate structure, we have observed.

Scans were made along (Π, Π) in the same manner as for YBCO with the k_f held perpendicular to the scanning direction. Since the direction perpendicular to the scan is defined only in that it is perpendicular to (Π, Π) in the $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ case, it represents an average over (a^*, b^*) and c^* and directions in the plane between them. We are thus set up to observe either 1- or 2D-structure, but in the case of 2D structure we would only get a contribution for the case when the integration is along c^* .

Such scans yielded small peaks near the wave vectors $1/3$ and $2/3$ of (a^*, b^*) . The peaks were unobservable in the first zone and appeared to be larger at the $2/3$ position in the second zone. The restriction of keeping k_f perpendicular to the scan direction makes only two zones accessible for the incident energy that works best with the filter. Figure 1 shows the result of scans near 1.33 at three temperatures. The scans are the average of several measurements made to obtain the counting errors shown. The 10K scan was counted at different times for a couple of different scan meshes resulting in the variation of the error bars in the scan. The peak becomes weaker at 60K and is unobservable at 90K. The zone boundary is at $1/2$ or (Π, Π) along the scan direction so that the peaks are observed at positions near $2/3$ (Π, Π) .

The filter integration technique is excellent for discovering lower-dimensional inelastic scattering, but gives no information on the energy scale of the scattering. Therefore we undertook the time consuming task of using an analyzing crystal to scan energy at a number of steps around the 1.33 position. We were limited on

the low-energy side by having to avoid the elastic scattering, and on the high-energy side by the incoming neutron energy. Since very coarse energy resolution was needed to observe the incommensurate scattering, we could only make observations above about 25 meV and remain free of the intense elastic scattering. Energy scans were made for energy transfers between 25 and 40 meV. If the counts for these scans are added at each Q value we should recover the result obtained with the filter. Figure 3 shows the result of adding the counts for energy transfers between 25 and 40 meV for Q values in the neighborhood of 1.33 along (Π, Π) . The result at 35K is consistent with the low-temperature data in Fig. 2, while again there is no sign of a peak at 100K. The error bars are large as the peak counting rate is small.

The top of Fig. 4 shows the energy dependence obtained by subtracting the scans for the background at points away from the middle of the peak from the two highest peak points. Points have been binned in energy to improve statistics. The excess scattering does not appear to come from a particular energy. Rather, the scattering seems to come from all energies, with the high-energies contributing more. The bottom curve is a rough measure of the temperature dependence of the scattering taken using the filter and subtracting the background near the peak from the counts at the peak center. The peak is weak, so the counting errors are large. The measurement is consistent with scattering that disappears at T_c , although the exact temperature cannot be determined because of the large counting errors.

Additional experiments need to be done to further characterize the observed scattering. Indeed, the measurements shown can be regarded as preliminary and additional work is underway. It is possible that the scattering is magnetic in origin, although it appears unlikely. Measurements at higher Q values would confirm this. The temperature dependence of the scattering needs to be better determined to see if the scattering disappears at T_c or perhaps at some value T^* somewhat higher than T_c .

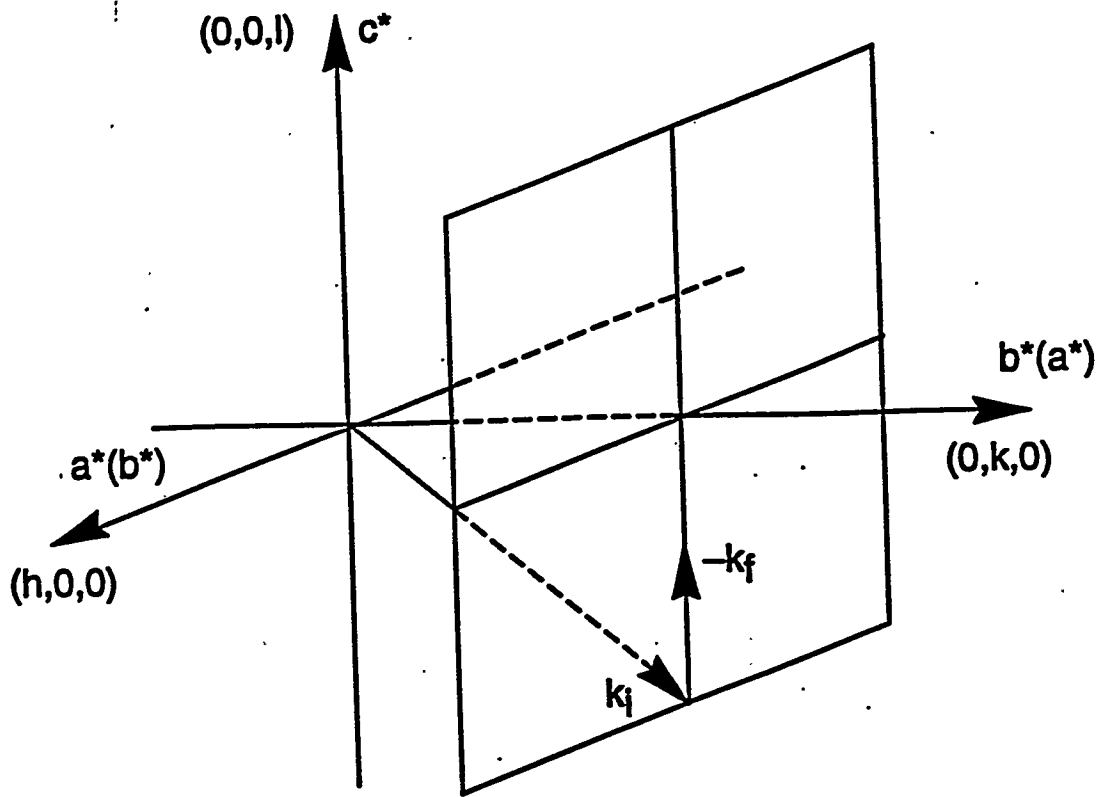
It is also not obvious how the observed excitations fit into the physics of the high- T_c problem. If the excitations result from a dynamic stripe phase there should be both incommensurate spin and charge peaks. So far we have not discovered any scattering in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ that we can confirm as being magnetic. The 1D nature of the sample limits the Q space that we can cover. It would also be desirable to examine other doping levels. The scattering is observed at a wave vector position that is very near $2K_F$ as determined from photoemission.⁵ The scattering could thus result from a Fermi surface effect and have nothing to do with stripes, or it could be both. Further experiments on $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ and other superconductors will clarify the situation. In principle, charge scattering should be observable with x-rays. In practice this is difficult for the high- T_c materials as x-ray scattering is dominated by scattering from the heavy elements, while the oxygen motion is likely to be the most important. It is also difficult to exclude elastic scattering with x-rays so that the measurements are dominated by the small lattice distortions found in the high- T_c materials. Neutron scattering appears to be the method of choice, although the weak signals require long counting times.

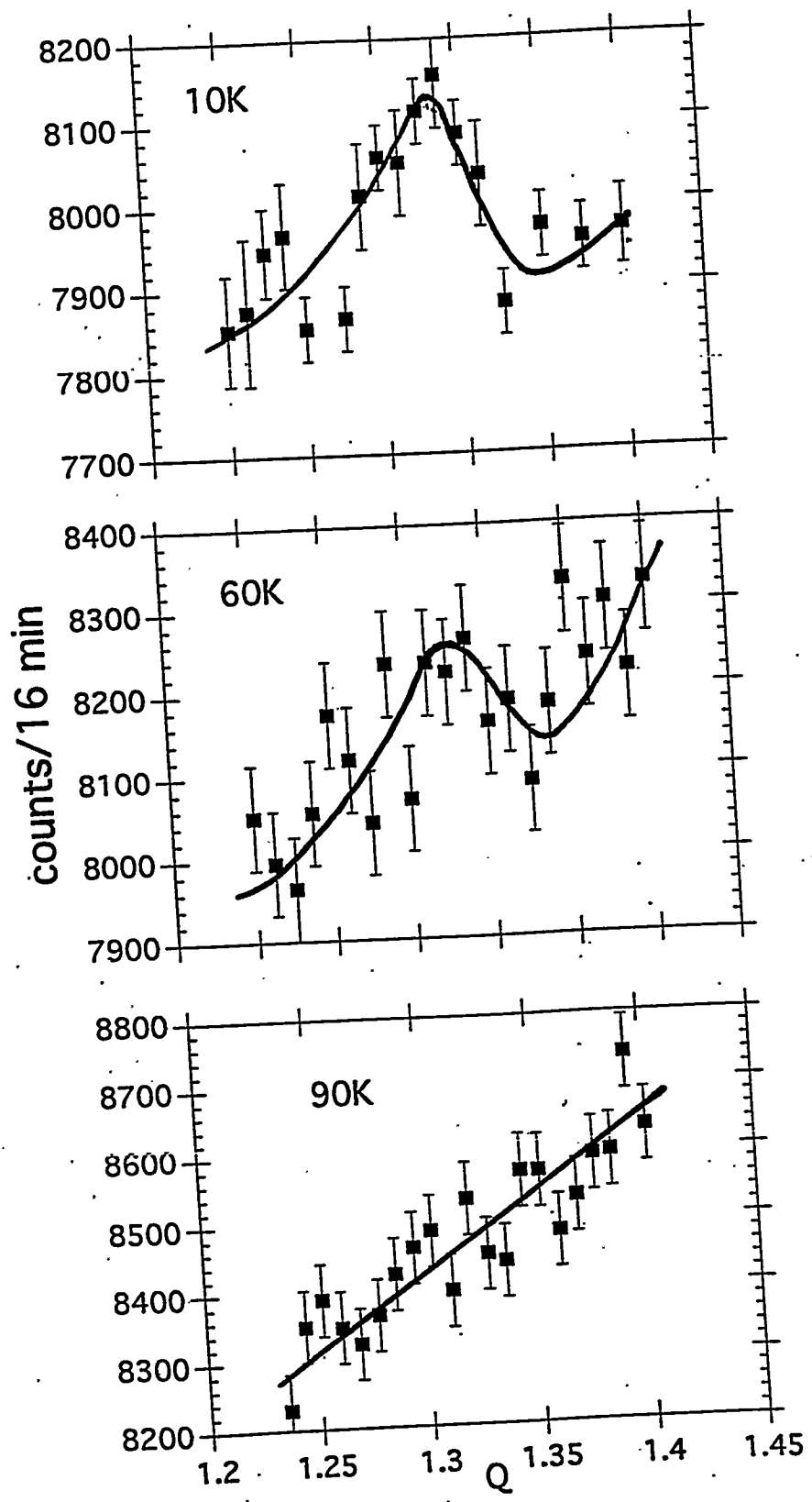
Figure Captions

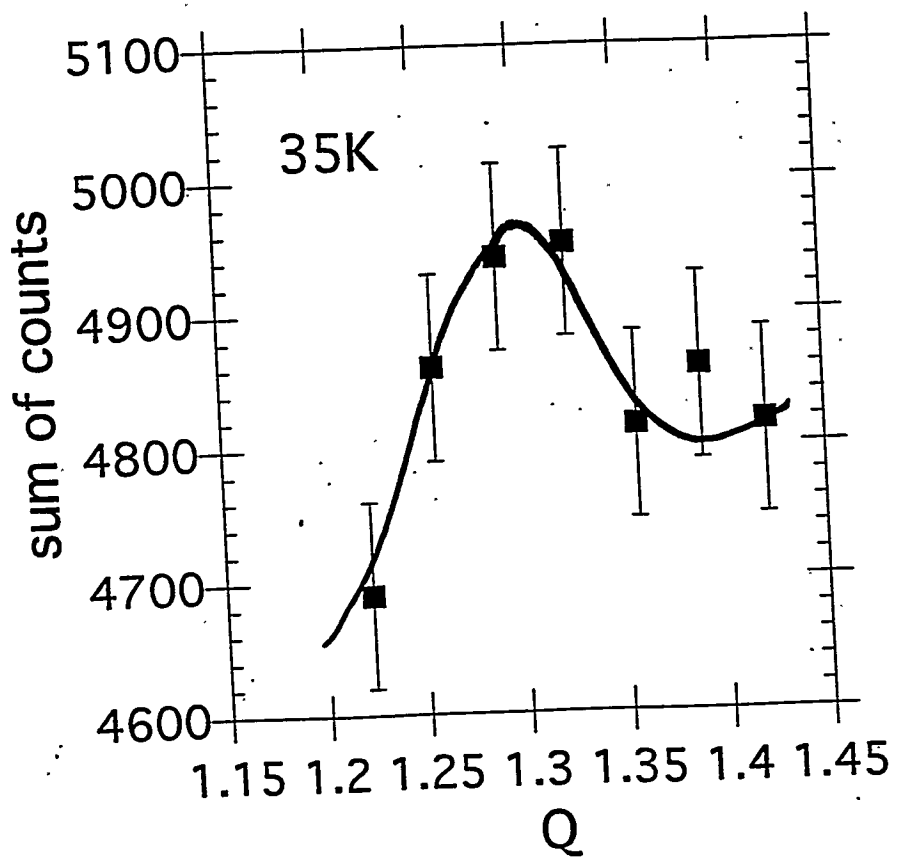
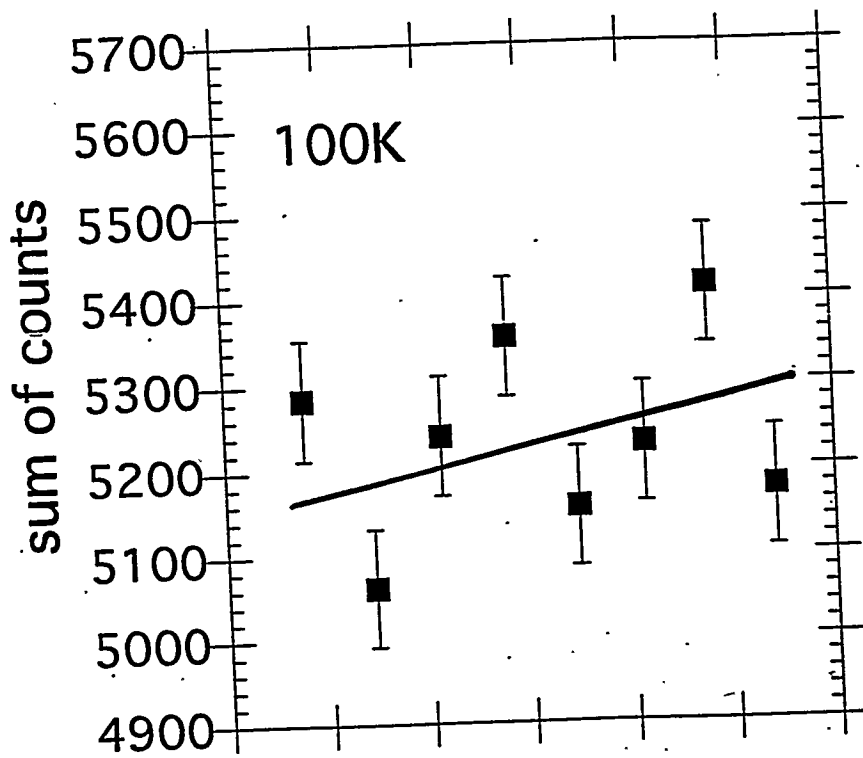
1. Scattering geometry used for the experiment. The scan direction is along a mixture of a^* and b^* directions as they are indistinguishable in the twinned sample. k_x is held perpendicular to the scan direction throughout the scan. In the filter mode energy integration takes place along k_x .
2. Data obtained from scans in the region near 1.33. In square lattice notation, 1.33 is $2/3$ of the way to the zone boundary position at (π, π) . A number of runs were averaged to obtain the error bars shown. No peak can be observed at 90K.
3. Data taken at points near 1.33 with the filter removed and the analyzer scanned over energy transfers from about 25 to 40 meV. The points in the energy scan were then added for each Q point measured and the result plotted. The result agrees well with Fig 1. where the filter is used. The weakness of the scattering produces fairly large error bars.
4. The top graph shows scattering at the two highest points for the 35K data minus the end points at various energy transfers. This shows the scattering does not stem exclusively from one energy, but rather occurs at all energies measured with the larger weight seeming to occur at higher energies. The bottom graph shows temperature dependent data obtained with the filter. The data for the points were determined by subtracting the background from the peak center. Again the weak scattering results in large error bars.

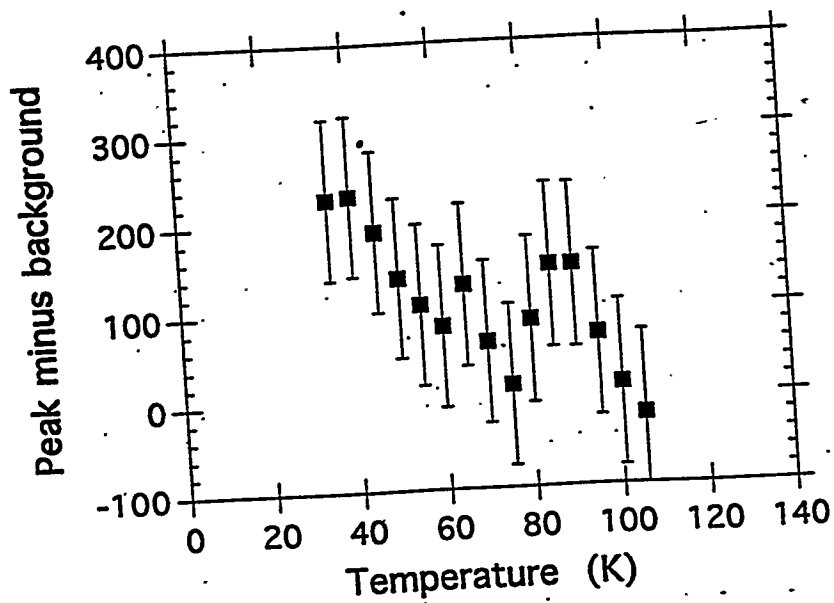
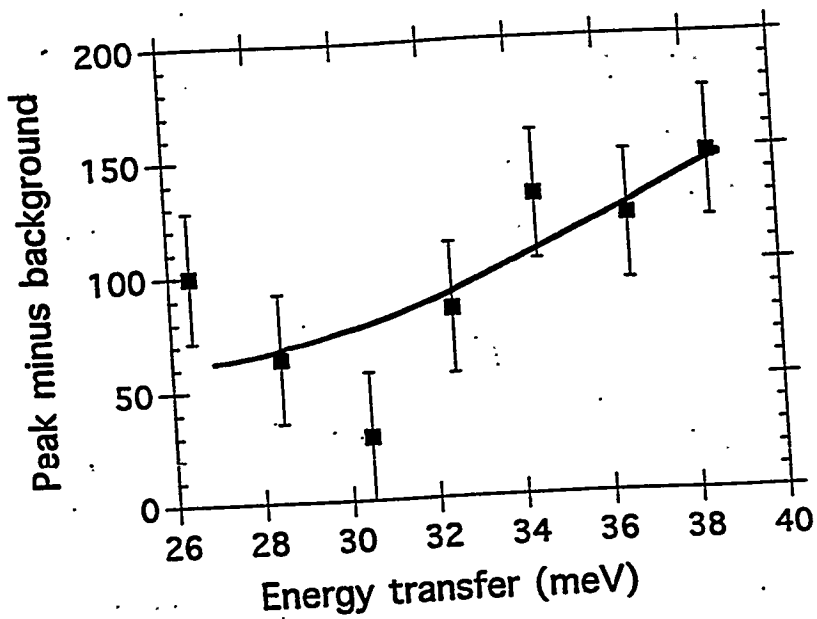
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