Proton NMR study of spin density wave thermal fluctuations in $(\text{TMTSF})_2\text{PF}_6$, where TMTSF is tetramethyltetraselenafulvalene

W.G. CLARK, M.E. HANSON, W.H. WONG and B. ALAVI

Department of Physics and Solid State Science Center, University of California at Los Angeles, Los Angeles, CA 90024-1547, U.S.A.

Abstract. — Measurements of the proton spin-lattice relaxation rate ($1/T_1$) at a pressure of 1 bar in a single crystal of $(\text{TMTSF})_2\text{PF}_6$ (TMTSF is tetramethyltetraselenafulvalene) are reported for the magnetic field in the range 0.25-1.48 T aligned along the b' - and c^* -axes over the temperature range 2-30 K. The methyl group rotation contribution to $1/T_1$ is subtracted to obtain the spin density wave (SDW) contribution. Through measurements of $1/T_1$ below and above the spin flop transition it is determined that phason fluctuations of the SDW are responsible for most of the relaxation. Depinning the SDW's by an electric field leaves $1/T_1$ nearly unchanged, which indicates that the SDW and its fluctuation rate near 10^8 rad/s persist when the SDW is sliding. Analysis of the peak in $1/T_1$ near 3 K on the applied magnetic field suggests that it represents a slowing of thermally activated fluctuations with an activation energy $\Delta/k_B = 18.3 \pm 4.0$ K, which is close to the single particle gap for this material. The contribution of critical fluctuations to $1/T_1$ is consistent with the transition being weakly first order. Unlike the relaxation in the ordered phase, the contribution of the critical fluctuations is isotropic and has little, if any dependence on magnetic field.

1. Introduction.

An important current problem in condensed matter physics is the nature of the broken symmetry phases and transitions that occur in low dimensional organic conductors. One such example is the spin density wave (SDW) state that forms in the Bechgaard salt, $(\text{TMTSF})_2\text{PF}_6$ (TMTSF is tetramethyltetraselenafulvalene), below the SDW transition temperature $T_S = 12.2$ K [1].

In this paper we present a detailed study of the fluctuations of the SDW at moderate values of the applied magnetic field ($0.25 \text{ T} > B_0 > 1.48 \text{ T}$) in $(\text{TMTSF})_2\text{PF}_6$ using the spin-lattice relaxation rate ($1/T_1$) of the methyl group protons at a pressure of 1 bar. An overall temperature range $2 > T > 30$ K is covered. Below about 13 K, $1/T_1$ is dominated by SDW fluctuations [2-4]. Between 13 K and 30 K, $1/T_1$ is caused mainly by methyl group rotation [3].

Prior NMR studies using protons [2-8], ^{13}C [9-11], and ^{77}Se [11-14] have revealed many important features of these fluctuations. From the more detailed study presented here, we are able to establish several features that were unclear or missing from the earlier work. These include (1) evidence that is consistent with the reports that the SDW transition in this material is weakly first order [15-17], (2) evidence that outside the critical regime the main contribution to $1/T_1$ is from phason fluctuations, (3) characterization of the frequency dependence of the fluctuation spectrum, (4) evidence that the "unusual" behavior often seen near 3.5 K is due to a slowing of the fluctuations [4, 6, 7], and (5) evidence that depinning of the SDW has no significant effect on the magnitude and high frequency fluctuations of the order parameter.

Proton NMR has proved to be a very useful tool in this study. It has features that complement those of ^{13}C and ^{77}Se NMR for this application. Because the proton signal has a much higher sensitivity, it is well adapted to detailed studies involving many repetitions and measurements at

low B_0 , where the different local field directions associated with the spin flop transition can be exploited to establish the type of SDW fluctuations that are responsible for nuclear spin relaxation. Another advantage of protons is that they constitute a weak probe of the SDW whose signal is not obliterated by the formation of the SDW, as is the case for ^{77}Se [11-14]. The two main disadvantages of protons in comparison to ^{13}C and ^{77}Se is that their location is moderately distant from the conduction electrons, with the consequence that they sense a rather complicated combination of hyperfine and dipolar interactions from the SDW [18]. Another comparative disadvantage of protons is that part of their relaxation at low temperatures is caused by methyl group rotation [3]. As shown below, this disadvantage is readily overcome for most of the temperature range over which SDW fluctuations play a significant role.

The primary content of the work reported here is to present our main experimental results that characterize the SDW fluctuations, and to point out their key features and consequences. A more quantitative analysis of these results will be presented elsewhere.

2. Experimental Results.

The sample used in these studies was a single crystal with approximate dimensions $5 \times 0.15 \times 0.15 \text{ mm}^3$ (about $200 \mu\text{g}$) prepared by standard electrochemical methods. It is the same one that has been used for measurements of the SDW order parameter [16, 17], the average displacement of the SDW by an electric field [19], and the dynamics of sliding SDW's [20]. Leads for passing current through it and measuring the sample voltage were applied to each end. It was inserted into a small NMR coil. A laboratory-built pulsed NMR spectrometer of conventional design was used for the T_1 measurements. Both the free induction decay and spin echoes were used to obtain $1/T_1$. The magnetic field was provided by a Varian electromagnet on a rotating base. The temperature (T) was generated by a temperature regulated flow of helium gas in direct contact with the sample above about 3.0 K and by direct immersion in liquid He for lower temperatures. Except for T within about 80 mK of the transition temperature ($T_S \simeq 12.2 \text{ K}$), a single exponential recovery of the proton signal was observed with a typical experimental uncertainty of about $\pm 4 \%$ for $1/T_1$. Because protons in the different methyl groups should have different coupling strengths to the SDW [5, 18], the appearance of a single value for $1/T_1$ indicates that proton spin diffusion is effective at establishing a single spin temperature for the proton system, thereby leading to a measured value of $1/T_1$ that is the average over the four methyl groups for a given field alignment. The use of a single crystal proved important because the contribution to $1/T_1$ by SDW fluctuations has a strong angular dependence [4].

Most of the measurements were done with two alignments of the magnetic field relative to the crystalline axes of the sample: the b' -axis and the c^* -axis. From visual observation supported by careful NMR spectroscopic measurements, we estimate that the crystalline a -axis is tipped about 5° from the rotation axis of the magnet, thereby introducing a comparable uncertainty into our stated alignment of the magnetic field.

The first data we present are measurements of $1/T_1$ above 12.5 K, where the main contribution is from methyl group rotation [3]. We apply a reasonable model for this part of the relaxation and then use it to obtain the SDW contribution that is the main focus of this paper. These data are summarized in Fig. 1, where $1/T_1$ as a function of T is plotted for two alignments of the external field (approximately parallel to the b' - and c^* -axes) for five values of B_0 (0.25 T, 0.35 T, 0.51 T, 0.90 T, and 1.48 T). In all of the figures, the data for B_0 along c^* - and b' -axes are indicated by the open and the solid symbols respectively. A fit to a phenomenological model is indicated by the solid lines. For this fit we assume that the relaxation rate is similar to the usual case of a thermally activated motion [21]. The particular form we use is

$$1/T_1 = \frac{A\tau}{1 + (\gamma B_0 \tau)^n}; \quad \tau(T) = \tau_0 \exp\left\{\frac{\Delta}{k_B T}\right\}, \quad (1)$$

where the parameters A , n (exponent), τ_0 ("attempt" period), and Δ (activation energy) are adjusted to fit the experimental data for $1/T_1$. The values represented by the solid lines are $n = 1.75$, $\tau_0 = 7.0 \times 10^{-12} \text{ s}$, $\Delta = 138\text{-}142 \text{ K}$, and $A = (4.6\text{-}5.3) \times 10^8 \text{ s}^{-2}$. The small range in Δ and A used for individual curves shows that there is little freedom in the choice of values for these parameters.

Several points are evident from Fig. 1: (1) Below 14 K there is a rapid rise above the smooth behavior at higher T that we associate with critical SDW fluctuations, (2) over most of the higher

Fig. 1

Fig. 2

Fig. 1. $-1/T_1$ for protons as a function of T above the SDW transition for several values of B_0 . Solid symbols: B_0 aligned along the b' -axis. Open symbols: B_0 aligned along the c^* -axis. Solid lines: model discussed in the text. The rise in $1/T_1$ below 14 K is from critical SDW fluctuations and that above 25 K is the onset of a peak near 58 K.

Fig. 2. $-1/T_1$ vs. T for $B_0 = 0.25$ T aligned along the c^* -axis.

Fig. 3. — Spin density wave contribution to $1/T_1$ for protons in $(\text{TMTSF})_2\text{PF}_6$ as a function of temperature for $B_0 = 0.35$ T (a, below spin flop), 0.51 T (b, above spin flop), 0.90 T (c), and 1.48 T (d). Solid symbols: B_0 along b' ; open symbols, B_0 along c^* . Because of the spin flop transition, all of data below 12 K in (a) have $B_S \parallel b'$. In (b)-(d), below 12 K $B_S \parallel b'$ for the open symbols and $B_S \parallel a$ for the solid symbols.

T range the model gives a reasonable fit to the data (we attribute the deviation above 25 K to the onset of the peak reported for $1/T_1$ near 58 K [3]), and (3) the methyl group rotation contribution to $1/T_1$ is the same for both directions of B_0 , which suggests that it is isotropic. The main consequence of this assignment for the methyl group rotation contribution is that it allows us to identify the SDW contribution to $1/T_1$. It is also seen that the methyl group rotation contribution falls so rapidly that it becomes negligible below ~ 10 K.

Figures 2-3 show the SDW contribution to $1/T_1$ as a function of T for $(\text{TMTSF})_2\text{PF}_6$ at several values of B_0 obtained by subtracting the methyl group contribution described above. The direction of B_0 is aligned along the b' - and c^* -axes of the crystal (solid and open symbols respectively). For these measurements, no electrical current was applied to the sample.

One set of measurements with an applied electric current (I) is shown in Fig. 4, where $1/T_1$ and the intensity of the NMR signal are plotted as a function of I ; $I_T = 0.25$ mA is the threshold value for depinning of the SDW. The small change in the NMR intensity shows that the increase in sample temperature is less than 20 % for currents up to an order of magnitude above the depinning threshold. The lack of a substantial change in $1/T_1$ is evidence that *for electric fields up to several times the SDW order and its fluctuations at $\omega_L \simeq 10^8$ rad/s are essentially unchanged by depinning.*

The angular dependence of $1/T_1$ at $B_0 = 0.35$ T and $T = 12$ K (close to $T_S = 12.2$ K) is shown in Fig. 5. Its significance is discussed in Section 3.

Fig. 4

Fig. 5

Fig. 4. — $1/T_1$ and NMR intensity for protons in $(\text{TMTSF})_2\text{PF}_6$ as a function of sample current up to values well above the depinning threshold $I_T = 0.25$ mA. The small variation in NMR intensity shows that heating is negligible and the lack of a change in $1/T_1$ indicates that the order of the SDW and its fluctuations near $\omega_L \simeq 1 \times 10^8$ rad/s are not changed significantly by depinning.

Fig. 5. — Angular dependence of the SDW contribution to $1/T_1$ for protons in $(\text{TMTSF})_2\text{PF}_6$.

3. Discussion.

Now we analyze the behavior of $1/T_1$ shown in Figs. 2 and 3 in terms of SDW fluctuations. The coupling of the protons to the SDW is through the magnetic field of the SDW (B_S), which has both dipolar and hyperfine parts in comparable amounts [18]. The Hamiltonian is [21]

$$\mathcal{H} = -\boldsymbol{\mu} \cdot \mathbf{B} = -\hbar\gamma I_z(B_0 + B_{Sz}) + \frac{1}{2}(I_+ B_{S-} + I_- B_{S+}), \quad (2)$$

where $\boldsymbol{\mu}$ is the proton magnetic moment, $\mathbf{B}$ is the total magnetic field at the nucleus, γ is the gyromagnetic ratio (42.57 MHz/T for protons), I is the nuclear spin operator, B_0 is the external magnetic field (defines the z -axis), I_+ and I_- are the nuclear spin raising and lowering operators, and $B_{\pm} = B_x \pm iB_y$. The effect of the SDW on the NMR absorption spectrum is given by the term B_{Sz} in Eq. (2) and the nuclear spin relaxation is driven by fluctuations in $B_{\pm}$, which are perpendicular to B_{Sz} and, therefore, perpendicular to B_0 .

The usual model for B_S is [1]

$$B_{Sj}(\mathbf{r}_j, t) = B_{Sj}(t) \cos[\mathbf{Q} \cdot \mathbf{r}_j + \phi(t)], \quad (3)$$

where j indexes the various rapidly rotating methyl group sites (position $\mathbf{r}_j$), $\mathbf{Q}$ is the SDW wavevector, and ϕ is the phase of the SDW, whose time dependence can be caused by thermal fluctuations and by displacements or sliding when an electric field is applied. Typical values of B_{Sj} are in the range 4-30 G. It varies among the inequivalent methyl group sites and with T [4, 5, 16-18].

In principle, there can be several excitation modes that contribute to the time dependence of $B_{Sj}(\mathbf{r}_j, t)$ [22]: phasons (fluctuations in ϕ), amplitons (fluctuations in the amplitude of B_{Sj} along its direction), and antiferromagnetic magnons (fluctuations in B_{Sj} perpendicular to its direction). Since ampliton fluctuations involve excitations across the single particle gap, it is expected that the energy to create phason and magnon excitations of the SDW is much lower than that to generate amplitude fluctuations [22]. We therefore drop amplitons from further consideration as a mechanism to explain the part of $1/T_1$ caused by SDW's. It should also be mentioned that the low dimensional electronic excitations discussed at length by Bourbonnais [23] do not play a role in the interpretation of the present experimental results. That contribution is overwhelmed in the metallic state by the methyl group rotation contribution and it does not apply to the relaxation in the ordered SDW state.

In Figs. 2-3, two types of contribution to $1/T_1$ can be identified: one part with a steep slope very close to T_S that is about the same for the two orientations, and another part starting just below T_S whose slope is lower and whose values for the two orientations differ significantly. We attribute the steep, isotropic contribution to $1/T_1$ near T_S to critical fluctuations associated with the SDW transition and the rest to non-critical fluctuations of the SDW.

First, we discuss the non-critical part of $1/T_1$. A key consequence of Eq. (3) is that only the fluctuations of $B_{Sj}(\mathbf{r}_j, t)$ perpendicular to B_0 contribute to $1/T_1$. On the basis of this fact, the angular dependence of $1/T_1$, and the spin flop (SF) transition in $(\text{TMSTSF})_2\text{PF}_6$ [24], it follows that except for the critical fluctuation regime very close to T_S (to be discussed later), the dominant relaxation mechanism for the protons is phason fluctuations. An important aspect of the SF transition, shown schematically in Fig. 6, is that below the minimum SF field of 0.48 T [24] (Figs. 2 and 3a), B_{Sj} is aligned close to the b' -axis for any orientation of B_0 (solid and open symbols). At higher fields (Figs. 3b-3d), B_{Sj} points along the b' -axis (solid symbols) when B_0 is along the c^* -axis and it points along the a -axis (open symbols) when B_0 is aligned with the b' -axis.

Fig. 6. — Schematic representation of the alignment of the SDW field (B_S) for different values and alignments of the external field (B_0).

Since B_{Sj} is perpendicular to B_0 for the open symbols (upper curves) in Figs. 2-3, for this alignment both magnon and phason excitations generate fluctuations of B_{Sj} (δB_{Sj}) that are perpendicular to B_0 ; i.e., in principle both are capable of causing proton spin-lattice relaxation. For B_0 along b' , however, the only excitation that can generate a δB_{Sj} perpendicular to B_S is a magnon. Since $1/T_1$ is much smaller for this orientation than for the other one, we conclude that the contribution of magnons is much smaller than that of phasons. (This conclusion assumes that magnon excitations below the spin flop field are not affected significantly by the direction of B_0). Because of the variation in the direction of B_{Sj} at the inequivalent methyl group sites [5, 18], there can even be a residual contribution from phasons for B_0 along b' which, if present, would further diminish an estimate of the magnon contribution. Thus, we identify phason fluctuations as the mechanism for essentially all of the relaxation in the upper curves in Figs. 2-3.

This assignment is supported by the angular variation of $1/T_1$ shown in Fig. 5. Because B_0 is below the minimum spin flop field, B_{Sj} remains close to the b' -axis as B_0 is rotated through the angle θ in the b' - c^* plane. Its component perpendicular to B_0 is proportional to $\cos \theta$, which implies a contribution to $1/T_1$ proportional to $\cos^2 \theta$ (solid line), in agreement with what is observed. It also implies that the smallest value of $1/T_1$ should occur for B_0 along the b' -axis, which is close to what is observed. The small deviation from the latter condition is consistent with the moderate variation reported for the direction of B_{Sj} [5, 18]. A consequence of this analysis is that magnon excitations play at most a minor role in the proton spin-lattice relaxation in the SDW state of $(\text{TMTSF})_2\text{PF}_6$ over the field and temperature range covered in this paper.

Since the data of Figs. 3b-d are taken above the minimum field for spin flop, the orientation of B_{Sj} for the lower curves (B_0 along b' , solid symbols) is along the a -axis. Under these conditions, both magnon and phason excitations have the correct polarization to cause proton spin-lattice relaxation. Because the magnon contribution to $1/T_1$ is negligibly small at 0.35 T and because a rather smooth variation of $1/T_1$ is observed as a function of T and B_0 , we conclude that below 12 K, phason excitations are the main mechanism for *all* of $1/T_1$ data we have presented. We speculate that the reduced value of $1/T_1$ for B_{Sj} along the a -axis reflects a smaller field amplitude, perhaps related to a different dipolar contribution for this orientation. More experimental work involving external field rotations out of the b' - c^* plane are needed to test this hypothesis.

There are three broad regions of the phason-induced proton spin-lattice relaxation with different characteristics to be discussed: (1) the region below about 4 K that has a field dependent peak above a rapid drop at lower temperatures, (2) the field dependent region above 9 K, and (3) the flat, nearly field independent region between these two temperatures.

It has been suggested that the peak in $1/T_1$ near 3.5 K reflects a phase transition of the SDW [4, 7, 25]. An alternative explanation of this peak supported by our data is that it is a dynamic effect. According to this picture, which we briefly outline here, there is a progressive slowing of the phason fluctuations as T is lowered. Such a process leads to a peak in the relaxation rate at the temperature T_{pk} when $\omega_L \tau = 1$, where $\tau(T_{pk})$ is the correlation time of small amplitude phason fluctuations [21]. For a thermally activated process, we use

$$\omega_L = \frac{1}{\tau(T_{pk})} = \left(\frac{1}{\tau_0} \right) \exp \left\{ - \frac{\Delta}{k_B T_{pk}} \right\}, \quad (4)$$

where $1/\tau_0$ is a constant. A semilogarithmic plot of ω_L as a function of $1/T_{pk}$ for points taken from Fig. 3 is presented in Fig. 7. The solid line is a fit to the data for $\Delta/k_B = 18.3$ K and $\tau_0 = 2.0 \times 10^{-11}$ s. Including the experimental error, we obtain $\Delta/k_B = 18.3 \pm 4.0$ K, which corresponds to the single particle gap for thermally excited carriers in this material [1]. This result suggests, in analogy with a model for incommensurate charge density wave dynamics when random pinning is present [26], that the phason fluctuations responsible for $1/T_1$ are a result of SDW condensate dissipation caused by its interaction with the "normal" electrons. More experimental

Fig. 7 – NMR frequency as a function of the inverse of the temperature of the peak in $1/T_1$ for protons near 3.5 K in $(\text{TMTSF})_2\text{PF}_6$.

work is needed to clarify this point.

We have also carried out a preliminary analysis of the value of $1/T_1$ at the peak, the details of which will be reported elsewhere. It is also consistent with the behavior of τ indicated in Eq. (4).

Near T_S , there is a field and temperature dependence to $1/T_1$ that can be characterized in the range 9-12 K by

$$1/T_1 = 0.35 \left(\frac{T}{10 \text{ K}} \right)^{3.65} \left(\frac{B_0}{1 \text{ T}} \right)^{0.8} \text{ s}^{-1}. \quad (5)$$

This expression, which is indicated by the solid lines in Figs. 2 and 3a-c, is just a fit to the data; it is not based upon a particular theoretical model, which must take into account the substantial change of the order parameter in this region and the temperature dependent SDW dynamics.

In the intermediate temperature range 4-8 K, $1/T_1$ is nearly independent of T and B_0 . This behavior presumably reflects an interplay of effects that involve the temperature dependence of the order parameter and the SDW dynamics.

Now we turn to the characteristics of $1/T_1$ we have identified with critical fluctuations close to T_S . Because of the uncertainty associated with the subtraction of the methyl group contribution, it is not possible to extract from our measurements a quantitative value for an exponent that characterizes the critical divergence of $1/T_1$ near T_S . There are, nevertheless, several characteristics of $1/T_1$ that can be used to infer properties of the SDW fluctuations in this region.

From the behavior of the SDW order parameter obtained from the NMR linewidth and other measurements, it has been variously suggested [15] and concluded [16, 17] that the transition is weakly first order, rather than second order, as is commonly assumed. Our $1/T_1$ measurements are consistent with this view. As T is decreased towards T_S , most of the data of Figs. 2-3 indicate a rapid rise that breaks to a near vertical slope at T_S . In the narrow temperature region of this steepest slope, we also find that there are unusually large fluctuations in the individual measurements used to obtain $1/T_1$. We interpret this anomalous "noise" in the measurements as caused by the jumps in the instantaneous nuclear spin relaxation rate that would occur if, because of small fluctuations in T during a measurement, the system shifts between the disordered state above T_S and the state with a finite order parameter below it.

One of the consequences of this situation is that *above* T_S , the divergence temperature for fluctuations lies *below* T_S ; below T_S , the divergence temperature for fluctuations is *above* T_S . The application of a simplified Landau model to this case [27] indicates that for $(\text{TMTSF})_2\text{PF}_6$, the difference between these two divergence temperatures is only about 0.1 K. Analysis of the contribution of critical fluctuations to $1/T_1$ near T_S should take this difference into account.

There are several other properties of the critical fluctuation contribution to $1/T_1$ that are suggested by our data: (1) it is isotropic, (2) it is nearly independent of ω_L , and (3) its contribution is about the same immediately above and below T_S . Even when the expected rapid temperature dependence associated with critical fluctuations is taken into account, the differences between their contribution to $1/T_1$ and that of the ordered state suggests that there is an important aspect of the ordered state that is not reflected in the critical fluctuations, perhaps because of the collective aspects of pinning or the spin flop condition in the ordered state. More accurate and extensive measurements in this range of T are needed to arrive at more definite conclusions based upon proton NMR measurements.

4. Conclusions.

We have reported extensive measurements of the proton spin-lattice relaxation rate at a pressure of 1 bar as a function of the value and alignment of the magnetic field (0.25-1.48 T along the b' - and c' -axes) and the temperature (2-30 K) in a single crystal of $(\text{TMTSF})_2\text{PF}_6$. By subtracting the methyl group rotation contribution, the part due to SDW fluctuations is identified. In the ordered phase the alignment of the SDW magnetic field associated with the spin flop transition is used to show that almost all of the observed relaxation by the SDW is caused by phason excitations. The persistence of the relaxation rate when the SDW's are sliding is evidence that the SDW order parameter and SDW fluctuations at the NMR frequency are not affected by SDW depinning up to electric fields several times the depinning threshold. Qualitative features of $1/T_1$ near T_S are consistent with the transition being weakly first order. It is also found that, unlike

$1/T_1$ in the ordered state, the contribution from critical fluctuations is isotropic and nearly independent of the NMR frequency.

Acknowledgements.

We thank S.E. Brown, G. Grüner, G. Kriza, E. Barthel, and P.A. Littlewood for helpful discussions regarding this work. Partial support for this project was provided by the UCLA Academic Senate Committee on Research.

- [1] For a current review of spin density waves in organic metals, see Grüner, G., *Rev. Mod. Phys.* (1993) to be published December, 1993.
- [2] Andrieux, A., Jérôme, D., and Bechgaard, K., *J. Phys. (Paris), Lett.* **42** (1981) L87.
- [3] Scott, J.C. et al., *Mol. Cryst. Liq. Cryst.* **79** (1982) 1.
- [4] Takahashi, T., Maniwa, Y., Kawamura, H., and Saito, G., *Physica (Amsterdam)* **143B+C** (1986) 417.
- [5] Takahashi, T., Maniwa, Y., Kawamura, H., and Saito, G., *J. Phys. Soc. Jpn.* **55** (1986) 1364.
- [6] Takahashi, T. et al., *J. Phys. Soc. Jpn.* **58** (1989) 703.
- [7] Takahashi, T. et al., in *Physics and Chemistry of Organic Superconductors. Proceedings of the ISSP International Symposium*, ed. by G. Saito and S. Kagoshima (Springer-Verlag, Berlin, Germany, 1990) p. 107.
- [8] Wong, W.H. et al., *Phys. Rev. Lett.* **70** (1993) 1882.
- [9] Azevedo, L.J., Schirber, J.E., and Engler, E.M., *Phys. Rev. B* **29** (1984) 464.
- [10] Barthel, E. et al., *Europhys. Lett.* **21** (1993) 87.
- [11] Wzietek, P. et al., *J. Phys. I France* **3** (1993) 171.
- [12] Azevedo, L.J., Schirber, J.E., and Engler, E.M., *Phys. Rev. B* **27** (1983) 5842.
- [13] Creuzet, F. et al., *Synth. Met.* **19** (1987) 1.
- [14] Bourbonnais, C. et al., *Phys. Rev. Lett.* **62** (1989) 1532.
- [15] Kang, W., Tomic, S., Cooper, J.R., and Jérôme, D., *Phys. Rev. B* **41** (1990) 4862.
- [16] Clark, W.G., Hanson, M.E., Wong, W.H., and Alavi, B., *Physica (Amsterdam)* (1993) to be published, 1993.
- [17] Brown, S.E. et al., (this conference) *J. Phys. (Paris), Colloq.* (1993) to be published
- [18] Delrieu, J.M. et al., *J. Phys. (Paris)* **47** (1986) 839.
- [19] Wong, W.H. et al., *Phys. Rev. Lett.* (1993) submitted March, 1993.
- [20] Clark, W.G., Hanson, M.E., Wong, W.H., and Alavi, B., *Physical Review B* (1993) to be published September 1.
- [21] Slichter, C.P., *Principles of Magnetic Resonance*, 3 ed. Springer Series in Solid-State Sciences, ed. P. Fulde. (Springer-Verlag, Berlin, 1990).
- [22] Psaltakis, G.C., *Solid State Commun.* **51** (1984) 535.
- [23] Bourbonnais, C., *J. Phys. I France* **3** (1993) 1532.
- [24] Miljak, M., Cooper, J.R., and Bechgaard, K., *J. Phys. (Paris), Colloq.* **44** (1983) 893.
- [25] Takahashi, T. et al., *Synth. Met.* **19** (1987) 1.
- [26] Littlewood, P.B., *Phys. Rev. B* **36** (1987) 3108.
- [27] Brown, S.E., unpublished.