To the Graduate Council:

I am submitting herewith a dissertation written by Edwin C. Jones entitled "Electrical Transport Properties of Epitaxial and Granular Oriented YBa$_2$Cu$_3$O$_{7-\delta}$ Thin Films." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Physics.

James R. Thompson, Major Professor

We have read this dissertation and recommend its acceptance:

[Signatures]

Accepted for the Council:

[Signature]

Associate Vice Chancellor and Dean of The Graduate School
ELECTRICAL TRANSPORT PROPERTIES
OF EPITAXIAL AND GRANULAR ORIENTED
YBa$_2$Cu$_3$O$_{7-\delta}$ THIN FILMS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

EDWIN C. JONES
December 1992
To my wife Gita and my son Jonathan
ACKNOWLEDGEMENTS

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ABSTRACT

Strong correlations between the Hall coefficient $R_H$, the transition temperature $T_c$, and the critical current density $J_c$ were established in a series of epitaxial YBa$_2$Cu$_3$O$_{7-\delta}$ thin films as a function of oxygen deficiency $\delta$. Steady increases in $R_H$ with $\delta$ suggests that deoxygenation reduces the density of states which, according to BCS theory, should lead to corresponding decreases in $T_c$. In contrast, two well-known plateaus occurring at 90K and 60K were observed in $T_c$ vs. $\delta$. Others have ascribed these plateaus to either electronic phenomena or oxygen clustering. We find that in the 90K plateau, the critical current density $J_c(\delta, H=0)$ decreases with $\delta$ and extrapolates toward zero at the edge of the plateau, while the relative field dependence of $J_c(\delta, H)$ is independent of $\delta$. Furthermore, a fluctuation analysis of the resistive transitions indicates a constant upper critical field $B_{c2}(0) = 110T$ across this plateau. These observations suggest that the oxygen clustering/percolation scenario occurs on the 90K plateau.

Moreover, computer simulations showed this oxygen clustering/percolation picture to be a plausible explanation for the occasional observation of a sign reversal of $R_H$ near $T_c$. For large oxygen deficiencies ($\delta > 0.5$) and for the granular oriented YBa$_2$Cu$_3$O$_{7-\delta}$ thin films, rapid decreases in $J_c$ with applied field were observed which is reminiscent of the conventional granular alloys. In addition, the self-field critical current densities $J_c$ behaved as SNS weak link systems in a Josephson mixed state. In sum, due to the short coherence length $\xi$ in these materials, many properties formerly believed to be "intrinsic" in nature are apparently "extrinsic" in nature.
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<th>Symbol(s)</th>
<th>Description</th>
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<tbody>
<tr>
<td>(A_t)</td>
<td>&quot;Stokes&quot; area</td>
<td>Cu(2)</td>
<td>&quot;plane&quot; site copper</td>
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<tr>
<td>&quot;a&quot;</td>
<td>aged</td>
<td>Cu(3)</td>
<td>&quot;plane&quot; site copper</td>
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<td>(a, b; c)</td>
<td>lattice dimensions</td>
<td>(\gamma)</td>
<td>anisotropy parameter</td>
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<tr>
<td>(\alpha)</td>
<td>relative scaling factor</td>
<td>(d)</td>
<td>radius of a fluxoid</td>
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<td>(\alpha^2 \text{tr} F(\omega))</td>
<td>electron-phonon spectral function</td>
<td>(\Delta(0))</td>
<td>superconducting energy</td>
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<td>(B)</td>
<td>magnetic induction</td>
<td>(\delta)</td>
<td>oxygen deficiency</td>
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<td>(B_{\text{c1}})</td>
<td>lower critical field</td>
<td>(\delta(\epsilon-\epsilon_F))</td>
<td>Dirac function</td>
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<td>gradient operator</td>
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<td>irreversibility field</td>
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<td>magnetic field constant</td>
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<td>(B^*)</td>
<td>field at which the flux lattice melts</td>
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<td>(b_{c\Omega}, b_{s\Omega})</td>
<td>bosonized charge/spin fluctuations</td>
<td>(E_\Omega)</td>
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<td>(\Omega)</td>
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<td>characteristic field (proportional to (f_0))</td>
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<td>speed of light</td>
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<td>critical current density in absence of flux creep</td>
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<td>$f_i$</td>
<td>volume fraction of $i$-th phase</td>
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<td>&quot;attempt&quot; frequency</td>
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<td>Fermi–Dirac distribution</td>
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<td>$dl$</td>
<td>integration increment</td>
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<td>$l$</td>
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<td>mean free path</td>
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<td>mass</td>
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<td>$T$</td>
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<td>$T$</td>
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<td>$v_F$</td>
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<td>$\nabla T$</td>
<td>thermal gradient</td>
<td>$v(k)$</td>
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<td>mean field transition temperature</td>
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<td>$T_c$ distribution width</td>
<td>$\Phi_0, \phi_0$</td>
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<td>$T_D$</td>
<td>Debye temperature</td>
<td>$x, 7-\delta$</td>
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<td>$\tau_{tr}$</td>
<td>&quot;transport&quot; relaxation time</td>
<td>$\Omega_0$</td>
<td>normalization volume</td>
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xx
## B. ABBREVIATIONS

<table>
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<tr>
<th>Abbreviation</th>
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<tr>
<td>BCS</td>
<td>Bardeen, Cooper, and Schrieffer</td>
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<td>CGR</td>
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<td>current-voltage characteristics</td>
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<tr>
<td>SIS</td>
<td>superconductor–insulator–superconductor</td>
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<tr>
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<td>Y–123</td>
<td>YBa$_2$Cu$<em>3$O$</em>{7-\delta}$</td>
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<tr>
<td>YBCO</td>
<td>YBa$_2$Cu$<em>3$O$</em>{7-\delta}$</td>
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I. INTRODUCTION

The electrical transport characteristics of a series of epitaxial and polycrystalline YBa$_2$Cu$_3$O$_{7-\delta}$ thin films were studied at the Oak Ridge National Laboratory’s Solid State Division. This study was motivated by the desire to understand the mechanisms limiting the critical current density, $J_c$, in both the epitaxial and granular thin films. Since the recent discovery of this new class of high-$T_c$ (transition temperature) superconductors, researchers have continued to make improvements in these materials in the hopes that someday the important superconducting properties such as $J_c$ will approach those of the earlier conventional superconductors, but at liquid nitrogen temperatures instead of the more expensive liquid helium temperatures. Liquid helium currently costs about $5.00 per liter as compared to $0.18 per liter for liquid nitrogen. Each class of thin films could have many potential applications with only a few examples stated here. With the ease of growing long polycrystalline superconducting tapes, these materials may someday lead to the production of superconducting cables. However, the critical current densities occurring at the grain boundaries in these polycrystalline materials are limited to values well below those for high quality epitaxial films. Therefore, more immediate emphasis has been placed on the improvement of the epitaxial films. Potential uses for the epitaxial films include interconnects in integrated circuits and other devices such as bolometers. Future research magnets and motors could potentially be developed by either type of material, given a little luck with breakthroughs. This dissertation summarizes the findings for epitaxial and granular thin films, in the hope that these results may help others in
fulfilling such breakthroughs.

At present, YBa$_2$Cu$_3$O$_{7-\delta}$ is the most extensively studied high-$T_c$ superconductor due to its early discovery and relative ease of processing. It was discovered in December 1986 by Chu et al.\(^5\) and has a transition temperature of about 92K near full oxygenation ($\delta \approx 0$). Like most other high-$T_c$ superconductors, YBa$_2$Cu$_3$O$_{7-\delta}$ is a perovskite derived material having the structure shown in Figure 1. However, this material is more complicated than the other high-$T_c$ materials since, YBa$_2$Cu$_3$O$_{7-\delta}$ has a "chain" copper–oxygen layer structure in addition to two "plane" layers. Both the "chains" and "planes" are believed to contribute to the normal state properties. Moreover, it is generally believed that the "planes" are responsible for the superconductivity, whereas the presence of the "chains" simply improves the superconducting performance by providing additional charge carriers to the "planes." Neutron diffraction data taken on oxygen deficient samples show that the oxygen loss primarily occurs in the "chain" sites, e.g., O(1) sites, whereas the "plane" sites are unaffected.\(^6\) However, the superconducting properties are known to change dramatically upon removal of oxygen, supporting the idea of charge transfer between the "chains" and "planes." Therefore, one approach to studying the effects of carrier density on the superconducting performance, i.e., critical current density $J_c$ and transition temperature $T_c$, becomes possible in YBa$_2$Cu$_3$O$_{7-\delta}$. As a result, this project uses the Hall effect to detect relative changes in the carrier density while making comparisons to the superconducting performance.

Before proceeding, it is useful to present the theoretical electronic band structure
Accepted atomic structure of $\text{YBa}_2\text{Cu}_3\text{O}_7$ determined from neutron diffraction. The solid bars help to denote the Cu–O chains and the Cu–O$_2$ planes. This "orthorhombic" structure has the dimensions $3.822 \, \text{Å} \times 3.885 \, \text{Å} \times 11.680 \, \text{Å}$. The inset shows the corresponding Brillouin zone. Source: H. Krakauer, W. E. Pickett, and R. E. Cohen, J. Supercond. 1, 111 (1988).
for YBa$_2$Cu$_3$O$_7$. These calculations were first performed by Krakauer et al.\textsuperscript{7} at the Naval Research Laboratory in Washington, D.C. using the linearized augmented plane wave (LAPW) method. The assumed lattice parameters used in this procedure were as follows: $a = 3.822$ Å, $b = 3.885$ Å, and $c = 11.680$ Å. The resulting band structure is shown in Figure 2. From this, it is apparent that four bands cross the Fermi level in YBa$_2$Cu$_3$O$_7$, and the corresponding Fermi surfaces are shown in Figure 3. Before the Santa Fe conference in 1991, few people believed these results due to the immense complexities involved in performing these calculations. However, recent experimental evidence from various types of measurements directly confirms the accuracy of these Fermi surfaces.\textsuperscript{8} Moreover, these band structures lead to interesting electronic DOS features. The calculated total and partial DOS [Figure 4] reveal two interesting features. First, the planar oxygen states, e.g., O(2) and O(3), have nearly identical DOS indicating that the orthorhombic distortion ($a \neq b$) has little effect on the chemical environment of the Cu–O$_2$ planes. Second, most of the states near and just below $E_F$ are associated with the "chain" derived bands. Moreover, a striking peak associated with the "chain" related bands appears 0.085 eV below $E_F$. Krakauer et al.\textsuperscript{7} points out that this feature is associated with only the O(1) and O(4) atoms. In addition, this feature is probably not coincidental and Yu\textsuperscript{9} showed that it simply dropped farther below the Fermi energy $E_F$ in the 60K phase of YBa$_2$Cu$_3$O$_{6.5}$. However, the physical significance of this DOS peak is not obvious at the present, but it is believed to be strongly associated with the normal state properties. As a result, a thorough study of the experimental data in the framework of these theoretical findings may shed some
Figure 2

Band structure of YBa$_2$Cu$_3$O$_7$ in the $k_z = 0$ plane near the Fermi level ($E_F = 0$). (a) States derived mainly from the "chains" are emphasized by the large symbols, whereas in (b), states derived mainly from the "planes" are emphasized by the large symbols. Note that most of the states within 0.5 eV of the Fermi energy are "chain" derived states. Source: H. Krakauer, W. E. Pickett, and R. E. Cohen, J. Supercond. 1, 111 (1988).
Fermi surfaces for the four bands crossing the Fermi energy $E_F$. The left half represents the bands occurring at $k_z = 0$, whereas the right half represents the bands at $k_z = 0.5$. The top and bottom panels depict the "chain" derived bands which, show a quasi-one dimensional character, whereas the middle panels depict the "plane" derived bands which, are more two dimensional. The solid lines represent the calculated value of $E_F$, and the short (long) dashes represent the displacement due to 0.2 fewer (more) electrons. Hence, these differences reflect the band masses. Source: H. Krakauer, W. E. Pickett, and R. E. Cohen, J. Supercond. 1, 111 (1988).
Total and partial electronic densities of states (DOS) of YBa$_2$Cu$_3$O$_7$ near the Fermi energy $E_F$ derived from the band structure results. Top panel, total DOS; second panel, Cu(1) [solid] and Cu(2) [dashed] DOS; third panel, O(1) [solid] and O(4) [dashed] DOS; bottom panel, O(2) [solid] and O(3) [dashed] DOS. Note the striking peak just below $E_F$ involving only the "chain" related states. Source: H. Krakauer, W. E. Pickett, and R. E. Cohen, J. Supercond. 1, 111 (1988).
light as to the actual significance of these features.

Early experimental work on oxygen deficient YBa$_2$Cu$_3$O$_{7-\delta}$ led to the discovery of two plateaus in $T_c(\delta)$ that are now well known.$^{10}$ More recently, it was found that these plateaus are absent in samples prepared by rapid quenching from high temperatures.$^{11,12}$ Although the origin of these features has proved difficult to elucidate, several elaborate electronic models have been proposed that rely either on a two-gap mechanism$^{13}$, or on charge transfer from the Cu–O chains to the Cu–O$_2$ planes.$^{14,15}$ However, magnetic hysteresis studies clearly show anomalous "fish tails" that have been attributed to defect clustering in oxygen deficient bulk samples.$^{16,17}$ Electron diffraction studies$^{18,19}$ and one neutron diffraction study$^{20}$ have suggested that a discrete series of ordered superstructures, with small differences in oxygen deficiency $\delta$, are simultaneously present only in the $\delta$-range of the plateaus. If the size of such domains exceeds that of the coherence length $\xi$ ($\sim 20\text{Å}$), then these domains should exist with distinct $T_c$ values. A fundamental understanding of the plateaus requires knowledge of the nature of these domains. If regions of distinct $T_c$'s exist, experiments inducing finite electric fields would tend to generate normal currents, thereby averaging over the phase distribution. On the other hand, transport studies at the limit of relatively small electric fields ($1 \mu\text{V/cm}$) would greatly emphasize the phase(s) with the highest critical current densities $J_c$, providing insight into the validity of the phase-separation scenario.

In the epitaxial thin films studied here, correlations were examined between the Hall coefficient $R_H$, $T_c$, and $J_c$ in a series of eleven epitaxial thin films that were
rendered oxygen deficient by thermal processing under controlled conditions. The results presented here are based on two samples representative of the highest quality thin films. Moreover, to better understand the origin of the $T_c(\delta)$ plateaus and to provide clues as to the possible pairing mechanism, systematic changes in the fluctuation regime of the resistive transitions $\rho(T,H)$ and the transition temperature $T_c$ as a function of oxygen deficiency $\delta$ in two of these epitaxial thin films were also examined. This allowed the determination of the upper critical field $H_{c2}$ as a function of oxygen deficiency $\delta$ by application of the high field fluctuation theory of Ullah and Dorsey\textsuperscript{21} to the experimental data. In these two films, a plateau in the slope of the upper critical field $dH_{c2}/dT = -1.7$ T/K, was found for $H \parallel c$. This result supports the applicability of the clean limit of BCS theory. On the contrary, the fluctuation theory did not accurately describe the transitions off the 90K plateau. This failure off the 90K plateau will be attributed to an extrinsic broadening of the transitions, arising from gross inhomogeneities in oxygen content for $\delta > 0.2$. Data will be presented to support the existence of such inhomogeneities off this $T_c$ plateau, i.e., $\delta > 0.2$, which appears to occur in all of the epitaxial thin films.

The Hall effect has been of considerable interest in the high-$T_c$ superconductors, due not only to the unusual temperature dependence,\textsuperscript{22,23} but also to the change in the sign of the Hall coefficient $R_H$ sometimes observed near $T_c$.\textsuperscript{24,25} Several explanations have been offered to explain this sign reversal of the Hall coefficient,\textsuperscript{26,27,28} which appears mostly in impure\textsuperscript{29,30} and in polycrystalline samples.\textsuperscript{24} In the eleven epitaxial films (two laser ablated and nine coevaporated) of
YBa$_2$Cu$_3$O$_{7-\delta}$ used throughout this work, the sign reversal was not universally observed. In fact, only the sample having the highest $J_c$ [a laser ablated film with an irreversibility field $B_{irr}(H//c) = 4.5 \text{T at } 77\text{K}$ and a critical current density $J_c(77\text{K}) = 5 \times 10^6 \text{ A/cm}^2$] showed a sign reversal of $R_H$ near $T_c$. Moreover, the highly crystalline, coevaporated films with lower defect pinning never exhibited a sign reversal of $R_H$ near $T_c$ at any applied field.\textsuperscript{31} This is perplexing, as most intrinsic flux creep models describing this sign reversal predict that these effects should be observed only in the limit of weak pinning energies.\textsuperscript{26} To pursue this issue, a study was initiated where the sample was annealed at various oxygen partial pressures at $550^\circ\text{C}$ followed by slow cooling to vary the oxygen deficiency $\delta$. After ten anneals, a final anneal at 1 atm $O_2$ returned the sample to full oxygenation. All of the starting properties, i.e., the resistivity $\rho$, $R_H$, $J_c$, and $T_c$, returned to their original values except for the superconducting Hall effect transition which no longer exhibited a sign reversal near $T_c$. Therefore, the random appearances of these sign reversals of $R_H$ near $T_c$ upon annealing prompted further investigation into the possibility of extrinsic mechanisms such as current percolation.

As for the granular thin films, a self-consistent critical current model in the Josephson mixed state is proposed for a series of $c$-oriented, polycrystalline and for a series of epitaxial triaxially-oriented YBa$_2$Cu$_3$O$_{7-\delta}$ thin films. The flux pinning activation energies were experimentally determined from electrical transport measurements over a wide range of temperatures and were found to behave quite differently for the two types of granular films. With the derived activation energies
applied to an SNS weak-link system, thermally activated flux motion is shown to reproduce the experimentally measured critical current densities.

Overall, the present study answers many questions regarding the *intrinsic* or *extrinsic* nature of some properties of YBa$_2$Cu$_3$O$_{7-\delta}$. Many effects such as the sign reversals of $R_H$ near $T_c$ and the $T_c(\delta)$ plateaus appear to be *extrinsic* in origin, rather than *intrinsic* as previously thought. Earlier work on the I–V characteristics at the Naval Research Laboratory supports this argument.\cite{32} Like the fully oxygenated polycrystalline thin films, increasing the oxygen deficiency ($\delta > 0$) in the epitaxial films appears to create a weak link array of superconductor-normal metal-superconductor (SNS) junctions, probably due to clustering or inhomogeneous distributions of the oxygen atoms. Therefore, careful thought must be placed upon any new observations before deciding whether or not these observations are *intrinsic* properties in this new class of superconductors. Finally, the results of this dissertation were already made public in several oral talks\cite{33,34,35,36} and scientific articles,\cite{37,38,39,40} either published or as preprints awaiting clearance for publication.
II. EXPERIMENTAL ASPECTS

A. Overview of the Most Important Procedures

The epitaxial thin films used in this study were grown either by the BaF₂ process⁴¹ or by pulsed laser ablation⁴² onto LaAlO₃ substrates. For electrical transport measurements, the c-axis perpendicular films were photolithographically patterned with a 3 mm long by 50 μm wide bridge containing two opposing 20 μm wide Hall terminals. Six gold dots were then sputtered onto contact areas to allow simultaneous measurements of the resistive and Hall signals using standard dc techniques [see Figure 5]. Note that the use of inert gold contacts avoided the problems associated with sample contamination during the reannealing of these samples. Currents were systematically reversed to eliminate thermal emfs. Contact resistances were typically less than 0.1 mΩ after the first full oxygenation anneal at 550°C in 1 atm O₂. This allowed easy, solder-free mounting and demounting with the use of Au–In–Au pressure pads and spring loaded "pogo" contacts. To control the oxygen deficiency δ, sequential isobaric anneals⁴³ at 550°C were conducted under reduced partial pressures of O₂ [see Figure 6(a) and Figure 6(b)]. Thus, small changes in Tc, Jc, and RH as a function of δ could be obtained in a given sample of fixed bridge geometry, thereby eliminating the relative errors due to cross sectional differences which exist between samples. The effects of oxygen depletion were reversible, as demonstrated by a final anneal at 1 atm O₂ that reestablished the starting properties of the films even after eleven sequential anneals. To eliminate offset voltages due to the
Figure 5

Typical current bridge pattern for the thin films used throughout this study. The transport bridges were photolithographically defined as 3 mm x 50 μm; these bridges contained two opposing 20 μm wide Hall terminals. Afterwards, six gold contacts (dark regions) were sputtered onto the samples. In general, resulting contacts had contact resistances of not more than 0.1 mΩ each.
Method of control of the residual oxygen deficiency $\delta$. (a) The oxygen deficiencies were controlled by sequential anneals at 550°C, followed by the slow cooling shown. Flowing Ar+$O_2$ mixtures allowed easy control of the resulting oxygen content, since $\delta$ depended on the partial pressure of $O_2$ chosen. 
(b) This was accomplished with the furnace setup as shown. Note that the oxygen partial pressure was measured with an Ametek oxygen analyzer. Part (a) was adapted from R. Feenstra (unpublished).
physical Hall terminal mismatches and to the transverse-even field \( R_{TE} \) [nonzero for \( \delta > 0.5 \), see Figure 7], the Hall coefficient in the limit of low-field was defined by the difference of the Hall resistivities taken in opposing fields,

\[
R_H = \frac{\rho_{yx}(H) - \rho_{yx}(-H)}{2H}.
\]  

Moreover, in order to perform this subtraction, each temperature sweep was interpolated at 0.5 Kelvin intervals using the Lagrange method. Thus, these subtractions were easily accomplished as a function of temperature [Figure 8] within a Lotus spreadsheet. In addition, magnetic fields of 8 Tesla were applied parallel to the \( c \)-axis, and were verified to be in the low-field regime, since no saturation was observed in the \( R_H \) vs. \( B \) behavior through 8 Tesla\(^4\) while in the normal state at all oxygen deficiencies. More importantly, this "subtraction" procedure was utilized to determine the Hall coefficient in a copper test film patterned according to Figure 5. Fortunately, a temperature independent Hall coefficient \( R_H = -5.9 \times 10^{-11} \text{ m}^3/\text{C} \) was obtained, which agrees with the accepted value for copper.\(^4\) In sum, reliable values for the Hall coefficient in thin films can be obtained by utilizing the basic procedures outlined in this section.

**B. Estimation of Oxygen Deficiency \( \delta \)**

From systematic x-ray diffraction studies of four films, the following correlation between the relative change in the \( c \)-axis lattice parameter \( c \) and the normal state electrical conductivity \( \sigma \) was obtained for oxygen contents in the regime of the 90K
Transverse-even coefficients $R_{TE}$ observed in oxygen deficient $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (non-zero when $\delta > 0.5$). These signals are defined by\(^{44}\)

$$R_{TE} = \frac{\rho_{yx}(H) + \rho_{yx}(-H) - 2\rho_{yx}(H=0)}{2H^2}, \quad (2)$$

where $\rho_{yx}(H)$ is the "apparent" Hall resistivity at an applied field $H \parallel c$. Note that $\rho_{yx}(H=0)$ must be inserted to eliminate the offset signals due to physical misalignments of the Hall probes. Moreover, the resulting signals are "extremely weak" and would not have been detected without the computerized data acquisition system described in Section D. In addition, aging effects (discussed in Chapter IV) were observed for the composition $7-\delta = 6.35$. However, no theory in the low-field limit exists at present to explain the significance of these signals. Unfortunately, such non-zero signals require the application of Equation (1) in defining the Hall coefficient.
Example determination of the Hall coefficient $R_H$ as described in the text. The field reversal process (top half) followed by (1) a Lagrange interpolation of the data at 0.5K intervals and (2) the subtraction of these interpolated curves according to Equation (1) generates the defined Hall coefficient curve shown. Notice the complete disappearance of the "anomalous" bump in the superconducting transition.
plateau:

\[
\frac{\Delta c}{c_o} = (4.8 \pm 0.5) \times 10^{-3} \frac{\Delta \sigma}{\sigma_o}, \tag{3}
\]

where \(c_o\) and \(\sigma_o\) represent the fully oxygenated state.\(^{45}\) In bulk \(\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}\), the \(c\)-lattice expansion has been correlated with the oxygen deficiency \(\delta\) in the orthorhombic state according to the average results of Cava \textit{et al.} and Jorgensen \textit{et al.}:\(^{46,47}\)

\[
\frac{1}{c_o} \frac{\Delta c}{\Delta \delta} = +10.7 \times 10^{-3}. \tag{4}
\]

Combining Equations (3) and (4) leads to the result

\[
\delta \approx 0.45 \left| \frac{\Delta \sigma}{\sigma_o} \right|. \tag{5}
\]

Values of \(\delta\) obtained from Equation (5) must be regarded as provisional, since extrinsic factors such as substrate-induced strains may alter both the magnitude of the \(c\)-lattice parameter, as well as its response to \(\delta\). The values are quoted to provide a familiar and relative labeling of composition, but \textit{none} of the following analyses in this dissertation depend quantitatively on the precision of the values. With this proviso, Tables I and II tabulate experimental information associated with the determination of the \(\delta\) values for the two representative samples used in the figures throughout this work. Since Equation (5) generates a maximum value of only \(\delta = 0.45\), e.g., \(|\Delta \sigma/\sigma_o| \rightarrow 1\), this equation was utilized for the estimates of \(\delta\) only in the range in which the x-ray data were obtained, i.e., \(\delta \leq 0.3\). For larger oxygen deficiencies, \(\delta\) was based entirely on
Table I. Experimental data used in the determination of δ's depicted in the figures pertaining to the coevaporated thin film. The calculations of δ are described in the text and are rounded to the nearest 0.1. The letter "a" denotes "aged" at room temperature for 4 days before performing these measurements to avoid any "quenching" effects.

| Estimated 7-δ | Anneal Log(P_{O2}) | |Δσ/σ₀| (at 100K) | J_c(1.2K) [A/cm²] | T_c (at 0.01xR_N) |
|--------------|---------------------|-----------------|------------------|-------------------|------------------|
| 7.0          | 1 atm               | 0               | 1.47 x 10⁷       | 89.4K             |
| 6.9          | -0.60               | 0.201           | 7.40 x 10⁶       | 90.4K             |
| 6.8          | -0.97               | 0.430           | 3.16 x 10⁶       | 89.6K             |
| 6.7          | -1.56               | 0.650           | 6.50 x 10⁵       | 74.5K             |
| 6.6          | -2.14               | 0.678           | 1.58 x 10⁵       | 60.5K             |
| 6.5          | -2.50               | 0.702           | 1.00 x 10⁵       | 54.0K             |
| 6.4          | -3.00               | 0.903 (a)       | ≈ 1 x 10⁴        | 29.0K (a)         |
Table II. Experimental data used in the determination of \( \delta \)'s depicted in the figures pertaining to the laser ablated thin film. The calculations of \( \delta \) are described in the text and are rounded to the nearest 0.05. The letters "q" and "a" denote "quenched" from 200°C and "aged" at room temperature for 4 days, respectively. Limited \( J_c \) measurements were conducted at 1.2K to avoid burning out this sample.

| Estimated 7–\( \delta \) | Anneal Log(\( P_{O_2} \)) | \( |\Delta \sigma / \sigma_0| \) (at 100K) | \( J_c(1.2K) \) [A/cm\(^2\)] | \( T_c \) (at 0.01x\( R_N \)) |
|---------------------------|------------------------|---------------------------------|----------------------------|-----------------|
| 7.00                      | 1 atm                  | 0                              | \( 2.50 \times 10^7 \)       | 88.3K           |
| 6.95                      | -0.60                  | 0.110                           | N/A                        | 88.9K           |
| 6.90                      | -1.00                  | 0.210                           | N/A                        | 89.4K           |
| 6.85                      | -1.48                  | 0.355                           | N/A                        | 88.8K           |
| 6.80                      | -1.78                  | 0.460                           | N/A                        | 87.0K           |
| 6.70                      | -2.09                  | 0.645                           | N/A                        | 76.0K           |
| 6.50                      | -2.53                  | 0.719                           | N/A                        | 56.2K           |
| 6.45                      | -3.05                  | 0.835 (q); 0.824 (a)            | N/A                        | 38K (q); 42K (a) |
| 6.40                      | -3.25                  | 0.906 (q); 0.897 (a)            | N/A                        | 12K (q); 20K (a) |
| 6.35                      | -3.55                  | 0.967 (q); 0.963 (a)            | N/A                        | Insulating      |
the comparisons of $T_c$ to those published by Veal et al. and Jorgensen et al.\textsuperscript{15,47}

C. The Hall Cryostat

The electrical transport properties of the YBa$_2$Cu$_3$O$_{7-\delta}$ thin films were obtained using a custom designed cryostat built by Cryomagnetics in Oak Ridge, Tennessee. This cryostat contains a 10 Tesla superconducting magnet [Table III lists specifications] suspended in a vacuum insulated dewar. Moreover, this superconducting magnet was especially designed to operate in a "persistent" mode. This mode allows the magnet to operate without a power supply after the magnet is charged. This is accomplished by a superconducting "short" which is placed across the magnet leads near the magnet. Whenever the magnet is charged or discharged, a heater mounted against this "short" is activated causing the "short" to become normal. Thus, the charging (or discharging) current will not flow through this lead except when the heater is off. More importantly, such "persistence" modes allow very stable fields which are ideal for Hall effect studies. Moreover, the "persistent" mode minimizes liquid helium (LHe) boil-off due to the discontinued application of current to the magnet leads after the magnet is charged. In addition, other features minimizing liquid helium losses include (1) a liquid nitrogen (LN$_2$) jacket surrounding the liquid helium can and (2) a pair of vapor-cooled magnet leads. The liquid nitrogen jacket minimizes the thermal radiation load on the liquid helium bath whenever the magnet is cooled to 4.2 Kelvins. The helium vapor-cooled leads simply make the best use the helium boil-off gas by channeling this cold gas through the upper half of the current leads into the atmosphere. In sum, this
Table III. Specifications of the custom designed 10 Tesla superconducting magnet built by Cryomagnetics for Martin Marietta Energy Systems. The magnet consists of a coil of twisted multifilamentary NbTi wire in a copper matrix. The copper matrix used in the construction acts as a form of "quench" protection. Furthermore, the coil is completely epoxy impregnated to prevent any shifting of the wires during usage.

Superconducting Magnet Specifications
Serial Number C182-M

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<th>Specification</th>
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superconducting magnet system was found to be very efficient in measuring both the Hall coefficient $R_H$ and critical current density $J_c(H)$.

To control the sample temperature, this cryostat (called the *Hall cryostat*) can be operated in one of two modes. First, the sample can be submerged in either liquid nitrogen ($LN_2$) or liquid helium (LHe). The vacuum pump station shown in Figure 9 can then maintain a preset boiling point of either cryogen by controlling the vapor pressure. This is accomplished by placing a predetermined amount of gas in the ballast tank [Figure 9] which is turn controls the amount of suction placed by the diaphragm valve on the sample space. The advantages of this form of control include: (1) a high degree of temperature stability, and (2) minimization of sample heating at the resistive contacts by more efficient dissipation of generated heat into a liquid. However, the disadvantages include: (1) limited range over which the temperature can be controlled (e.g., $52K^{48} - 78K$ using $LN_2$ and $1.2K - 4.2K$ using LHe), and (2) possible "plugging" of the capillary valve with nitrogen ice when the magnet is operating at liquid helium temperatures while the sample is submerged in liquid nitrogen. The second form of temperature control, however, is more versatile and was used for performing the Hall measurements. This type of control utilizes a capillary valve and transfer tube which transfers a small, controlled amount of cryogen, usually LHe, from the magnet can to the sample space [see Figure 9]. Moreover, just before this cryogen enters the sample space, it first passes through a copper block fitted with a heater coil. The setpoint temperature of this copper block is maintained by a DRC-91C Lake Shore temperature controller as well as the flow rate through the capillary valve. More
Vacuum pump station and gas line diagram used with the Hall cryostat. This system is located at the Solid State Division of the Oak Ridge National Laboratory. The main features include (1) the "house" vacuum (mounted against wall) which can be used to control the boiling point of either LN$_2$ or LHe using a diaphragm valve, and (2) the capillary valve which transfers controlled amounts of either cryogen from the magnet can to the sample space. Either feature can accurately control the sample temperature.
importantly, the temperature controller is connected to the computerized data acquisition system which is discussed in more detail in the next section. Therefore, the Hall cryostat was very versatile in performing the measurements used in this dissertation.

Finally and most importantly, the sample temperature must be known to a high degree of accuracy at all times while collecting data. Unfortunately, no single thermometer can give accurate readings while subjected to magnetic fields over the entire range of temperatures utilized (1.2K - 300K). Therefore, two thermometers were mounted onto a copper block along with the sample being studied. These thermometers were: (1) a Wahl Pt film, and (2) a Carbon Glass Thermometer (Lake Shore Serial Number C5948). The Pt film thermometer typically operates with 1 mA of current and is useful at all temperatures above ~40K. Below this temperature, Pt film thermometers are affected by large magnetoresistances which lead to errors in the derived temperatures. Thus, for temperatures below ~40K, a Carbon Glass thermometer was used. At low temperatures, Carbon Glass thermometers are almost unaffected by applied magnetic fields. However, currents on the order of ~1 µA are required to prevent internal heating of these thermometers. The calibrated resistances of both thermometers are shown in Figure 10. In addition, both of these thermometer calibrations are loaded into two column ASCII files [resistance (ohms) vs. temperature (K)] for use by the data acquisition system. This allows the computerized data acquisition system to convert the thermometer readings into common units of Kelvins as the data is being collected. Thus, this process helps to avoid possible human mistakes involved in manually converting numerous readings required in these studies.
Figure 10

Thermometer calibrations utilized by the data acquisition system. (a) The Wahl Pt film calibration as a function of temperature. This thermometer is most useful above $\sim 40K$, since a significant magnetoresistance occurs in applied fields below this temperature. (b) The Carbon Glass thermometer calibration as a function of temperature. In contrast, this thermometer is most useful below $\sim 40K$, since the resistance changes rapidly with temperature in this regime. Fortunately, this thermometer has little magnetoresistance.
D. The Data Acquisition System

To obtain the high level of sensitivity required to accurately quantify the Hall coefficient, a computer controlled data acquisition system was developed over a period of 17 months. Interface of a computer to the instruments [Figure 11] made it possible to statistically average many sample readings taken over a short interval of time (e.g., ~4 readings per second), thereby eliminating most background noise sources. Moreover, the resulting computerized "automation" included an automatic current reversing procedure to eliminate the thermal emf's. In addition, rapid conversions from one set of units to another set of units was made possible during the actual data collection. Finally, an optional data interpolator using input temperature intervals was incorporated into the Hall acquisition program. More importantly, these tasks were accomplished with four separate (and user friendly) basic programs [listed in the Appendix] to cover every type of experiment conceived at the time of this work. These basic programs are

1. **DA-HALL.BAS** (to measure \(R_H\) and/or \(\rho\) versus \(T\) or \(H\)),
2. **DA-JCTH.BAS** (to measure \(J_c\) versus \(T\) or \(H\)),
3. **DA-IVT.BAS** (to obtain I–V curves), and
4. **DA-DRIFT.BAS** (to emulate a simple X–Y plotter).

Note that the fourth program simply records values from the "X" and "Y" voltmeters without actively controlling any instruments. This allows one to record data similar to X–Y plotters if new experiments are devised. Otherwise, one would have to wait until a new program was written in order to run the experiments with "noise" filtering.
Electronic block diagram of the computer controlled data acquisition system used in making Hall measurements. The actual software used by the computer is listed in the Appendix.
Finally, the operating principles of these programs are described below.

To activate the data acquisition system, type DA at the DOS prompt. (Note: user inputs will be denoted with bold characters throughout the rest of this section).

\[ C:\> DA. \]

This automatically loads the GW-Basic software package as well as the IEEE interface commands into the computer memory. At the OK prompt, load the program (see the selections above) you intend to use by typing, for instance,

\[ LOAD "DA-HALL.BAS" \]

followed by

\[ RUN. \]

At this point, the program will display the first of several setup menus [e.g., Figure 12]. Here the program will prompt you to connect the Keithley 199 scanner channels to appropriate input signals (e.g., thermometer, sample voltage, standard resistor, ...). Keep in mind that Figure 11 serves as a relevant guide for such connections when performing Hall measurements. (Note: the sample heat dissipation signal is the smaller set of sample current leads and the alt. signal is intended for resistivity signals when performing Hall measurements). In addition, the Keithley 181 nanovoltmeter will be connected to either the Hall probes (for Hall measurements), or the sample voltage (for \( \rho(T) \), \( J_c \), or I-V measurements). After completing all of the connections, verify that the IEEE GPIB addresses (selected with pin settings on the back of the meters) agree with the settings shown in this setup menu. In case of a discrepancy, either change the pin settings on the back of the meters (see manuals) or
Figure 12

(a) *** HARDWARE SETTINGS ***
1: X-INPUT: GPIB Address: 26   Meter ID: KEITHLEY 181/199/197
2: Y-INPUT: GPIB Address: 14   Meter ID: KEITHLEY 181/199/197

Set KEITHLEY 224 Power Supply GPIB Address to 19 and the Voltage Compliance to a Safe Value.

K-199 SETUP: Temp. signal ===> X-Channel # 1
Curr. signal ===> X-Channel # 2
Alt. signal ===> X-Channel # 3
Mag. current ===> X-Channel # 4
K-191 NANOVOLTMETER: Hall (or Rho) Signal

Reset LakeShore Temperature Controller & set GPIB address to 12

ENTER SELECTION # (<C/R> TO CONTINUE):

(b) *** HARDWARE SETTINGS ***
1: X-INPUT: GPIB Address: 26   Meter ID: KEITHLEY 181/199/197
2: Y-INPUT: GPIB Address: 14   Meter ID: KEITHLEY 181/199/197
3: P-INPUT: GPIB Address: 11   Pwr Supp ID: Keithley 220 Power Supply

Meter Setup: X channel #1 ===> Thermometer Voltage Signal
X channel #2 ===> Sample Current Std. Resistor
X channel #3 ===> Sample Heat Dissipation Signal
X channel #4 ===> Magnet Curr. 1/100 Ohm Resistor
Y voltmeter ===> Sample Voltage

Reset DRC-91C & Set GPIB address to 12

ENTER SELECTION # (<C/R> TO CONTINUE):

Hardware Settings Menu for (a) DA-HALL.BAS and (b) DA-JCTH.BAS. This first program menu prompts the user to connect the various signals to the appropriate meter inputs. The menus for DA-IVT.BAS and DA-DRIFT.BAS are similar to these menus.
change the GPIB addresses in the program by typing 1, 2, or 3, followed by the new GPIB setting and a RETURN. Upon completion of this hardware setup menu, type RETURN to proceed.

At this point, the program will display a second menu entitled the SET-UP PARAMETERS menu. Examples of these menus are shown in Figure 13. Here, you can select an option number of a parameter that you intend to change (e.g., new thermometer calibration filename or a new scaling factor ...) followed by a RETURN. After all of the parameters meet your requirements, type a RETURN without a preceding option number to automatically begin the data acquisition sequence. Finally, a brief description of each set-up option is given below (note: the computer prompts are printed in upper case ITALICS for enhanced readability).

(1) FILENAME OF SETUP AND GRAPHICS PARAMETERS: This file contains the user parameters for all three menus saved from a previous run. Use of this feature is optional. Also, these files have the default directory C:\IEEE488\.

(2) X1-VOLTAGE SCALE FACTOR: Scaling factor necessary to convert the thermometer voltage reading to units of ohms, i.e., 1 / I_{thermometer}.

(3) X1-SIGNAL STEP SIZE: Minimum change required in the thermometer resistance before storing the current sample readings to the specified file.

(4) X2-SIGNAL SCALE FACTOR: Scaling factor necessary to convert the voltage measured across the standard resistor to units of amps, i.e., 1 / R_{std. ohms}.
Set-Up Parameters Menu for (a) DA-HALL.BAS and (b) DA-JCTH.BAS.
This second program menu prompts the user to enter various scaling factors and
various data filenames. Again, the menus for DA-IVT.BAS and DA-DRIFT.BAS are similar.
(5) **X3-VOLTAGE SCALE FACTOR:** Scaling factor for converting the channel #3 voltage into more useful units such as ohms. Only applies to DA-HALL.BAS.

(6) **Y-SIGNAL SCALE FACTOR:** Scaling factor for converting the nanovoltmeter readings into either units such as ohms, i.e., $1 / I_{\text{sample}}$, or units such as microvolts in case of $J_c$ or I–V measurements.

(7) **Y-SIGNAL STEP SIZE:** Minimum change required in the scaled nanovoltmeter reading (usually in ohms) before saving the sample readings to the specified data file.

(8) **Y-SIGNAL LIMIT:** The criterion of the scaled nanovoltmeter reading for defining the presently applied current as the critical current $I_c$. Typically defined as $1 \, \mu V / \text{cm}$. This feature applies only to DA-JCHT.BAS.

(9) **MAG. FIELD STEP SIZE:** Minimum change required in the magnetic field before saving the present readings (note: the program automatically converts the reading from channel #4 into units of kOe). This feature only applies when performing field sweeps of the Hall coefficient $R_H$ and/or the resistivity $\rho$.

(10) **X2-SIGNAL RANGE / STEP SIZE:** Three numbers (separated by commas when entered) defining the applied current sweeps in the DA-JCHT.BAS program. The first number represents the present applied current when attempting to measure $I_c$ across the sample. The second number is the maximum current that is allowed which halts the program execution if it is ever reached. The third number is the current step size fraction (typically 0.035

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meaning 3.5%) which increases the applied current by this fractional amount when attempting to reach the critical current $I_c$.

(11) **X2-SIGNAL BACKSTEP**: This number is the backup fraction (typically 0.05 meaning 5%) which decreases the applied current by this fractional amount whenever $I_c$ is reached. Only applies to the DA-JCTH.BAS program.

(12) **DATA FILENAME**: The filename in which the final data points will be saved to the hard disk. The extensions .dt0, .dt1, .dt2, ..., will be added automatically and consecutively. Moreover, the default directory is C:\IEEE488\data. Afterwards, you will be prompted to enter an optional title line which can consist of the date, sample ID, magnetic field orientation, etc.

(13) **THERM. CAL. TABLE FILENAME**: Optional filename of a two column wide ASCII table (ohms vs. T(K) listed with ascending ohms) containing the thermometer calibration. Current choices are **HC2PT** (for Pt Film) or **HC2CGR** (for CGR). The .CAL extension is automatically added. However, if this option is waived, thermometer resistances will be stored instead of Kelvins in the data file and the automatic temperature controller feature will be disabled.

(14) **TEMPERATURE INTERVAL BETWEEN DATA**: Minimum change required in the temperature reading (in Kelvins if a thermometer calibration file is specified) before the present $I_c$ value is stored to the specified file. Nevertheless, every time $I_c$ is reached, the computer will "beep" before starting the next current sweep. Note that this feature only applies to the
DA-JCTH.BAS program.

(15) **NO. OF SAMPLES IN DIGITAL FILTERING**: Number of readings to be averaged together in order to reduce the background noise. Typical values range from 1 to 5. Note that larger values should be avoided, since they tend to create shifts between the sample readings and the temperature readings. In the program DA-JCTH.BAS, values from 3 to 5 are preferred, since the calculated standard deviations of $I_c$ are computed using these numbers and stored with the data.

(16) **SCREEN GRAPHICS PARAMETERS SETUP**: Activates the capability of plotting data on the screen at the time of the data acquisition. If this feature is activated, an `<ACTIVE>` will appear in the menu. Typing this option automatically activates this feature and temporarily places you in a third (graphics) parameters menu. This menu is discussed later.

(17) **TRANSPORT CURRENT**: Current chosen for making the transport measurements when running the DA-HALL.BAS program. Typical entries are 1.000E-03 for Hall measurements and 1.000E-06 for resistivity measurements. Enter the number using the format shown in the menu, i.e., n.nnnE(sign)nn.

(18) **EXIT PROGRAM**: Saves the current parameter settings to the file specified in this setup menu (optional) and ends program execution. To return to DOS, type **SYSTEM** after exiting the program. Unfortunately, the IEEE interface commands will remain in the computer memory causing a significant reduction in the available memory unless the computer is rebooted.

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(19) *TEST CIRCUIT RESISTANCE:* Measures the total circuit resistance after prompting you to enter an estimated circuit resistance and a testing current. Warning: use this feature only when the sample is superconducting and use currents that are less than or equal to the expected $I_c$ or the sample may be "blown!" This circuit resistance is used in the DA-JCTH.BAS program to compute ongoing safe voltage compliances for the Keithley 228 power supply in an attempt to prevent overshooting of the applied currents.

(20) *$I_c$ OPERATING RANGE:* If "H" is specified, the Keithley 228 operates in a current limited mode. This mode is useful only for currents greater that $\sim 1$ mA. If "L" is specified, the Keithley 228 operates in a voltage limited mode which is useful for currents less than $\sim 10$ mA. When entering the latter mode, the program will prompt you to install a 1 k$\Omega$ resistor into the circuit.

(21) *TEMPERATURE CONTROLLER:* Toggles between <$ACTIVE>$ and <$INACTIVE>$ modes which enable or disable the computer control of the DRC-91C temperature controller, respectively. When this feature is activated, you will be prompted to enter three numbers separated by commas. The first and second numbers define the absolute limits allowed for the setpoints. For example, a lower limit of 83K is useful in preventing liquid nitrogen from flooding the sample space, if liquid nitrogen is being used as the cryogen. The third number represents the relative temperature of the cooling gas (either N$_2$ or He) with respect to the sample. In addition, this relative difference is automatically reduced by the program at lower temperatures, since the specific
heats are lower in this regime. More importantly, this feature must be utilized in order to obtain good temperature dependencies of the Hall coefficient. Typical numbers for the third parameter, called Vap-Samp, are ±15K, when using LN₂ as a cryogen, and ±35K, when using LHe as a cryogen.

(22) **INTERPOLATE FILE GIVEN IN OPTION 10...**: Interpolates the data file specified in Option #10 according to user input temperature specifications. To interpolate files not created by the DA-HALL.BAS program, make sure that these files contain 4 columns of ASCII numbers separated by either spaces or tabs where the first column is the temperature. Moreover, the first row is ignored, since it is considered to be a title; the second row must be a single number representing the total number of data rows, excluding the first two rows, contained in the array.

(23) **MAXIMUM HEATING ALLOWED**: This is a safety feature added to the DA-JCTH.BAS and DA-IVT.BAS programs which limits the amount of heating allowed at the sample contacts. To be useful, the second set of sample current leads, labelled I-I, must be plugged into scanner channel #3 as specified by the HARDWARE SETTINGS menu. A typical safety limit is not more that 50 mW. Even though the sample may not "blow" at low temperatures with this amount of contact heating, temperature errors will usually occur for heating in excess of ~3 mW below 20K. If the program detects excessive heating or excessive voltages across the sample (i.e., 100X the voltage criterion), the program displays a warning at the bottom of the screen and execution
temporarily halts. At this point you could either quit (by typing a Q), continue
(by hitting a RETURN), or enter a new heating limit followed by a RETURN.
This concludes the SET-UP PARAMETERS menu.

If the SCREEN GRAPHICS PARAMETERS SETUP option is chosen, a third
menu screen is displayed. Examples are shown in Figure 14. This menu is very
straightforward so that the excessive details can be left out here. However, in this
setup, you will be given options to change the X and Y plotting limits, an option to add
a graph title, and an option to plot a comparison graph (note: this file must be in the
same format as produced by these programs as described under the interpolation
option). Moreover, in DA-HALL.BAS, you are prompted with two additional options.
First, the x-axis can be either the temperature reading (in case of $R_H$ vs. temperature)
or the applied field (in case of $R_H$ vs. field). Second, the Keithley 199 channel #3 can
be included (denoted as *alt data*) in these plots. This is usually the resistivity signal
when obtaining Hall signals with the nanovoltmeter. Moreover, this signal is divided
by the *Ratio* shown in Option #9 before being plotted. Note that obtaining simultaneous
measurements of $R_H$ and $\rho$ are required in deriving accurate values of the Hall angle.
In addition, if the value of the standard resistor does not agree with that given in the
setup menu, the resulting error is more likely to be observed in the resistivity $\rho$ signal
rather than in the Hall coefficient $R_H$ signal. After completion of this graphics menu,
type a RETURN without an option number to return to the previous menu.

After all menu parameters are entered and the sample is ready to go, typing a
RETURN without an option number automatically starts the data acquisition sequence.
Screen Graphics Parameters Menu for (a) DA-HALL.BAS and (b) DA-JCTH.BAS. This third program menu prompts the user to enter the plotting limits and a comparison graphics filename. The menus for DA-IVT.BAS and DA-DRIFT.BAS are again similar. These parameters allow the user to plot data while the data is being obtained.
At this time, data is collected and stored directly to the specified file on the hard disk. Moreover, each program monitors the keyboard for occasional interrupts from the user where these interruption options are summarized below.

(A) RETURN: In DA–HALL.BAS and DA–DRIFT.BAS, this stores the current readings even if the minimum step sizes have not been satisfied. In DA–JCTH.BAS and DA–IVT.BAS, this halts the program execution and prompts you for a new starting current. Note that a significant period of time can be avoided in obtaining the first $I_c$ reading if this feature is utilized.

(B) Q: Ends the data acquisition sequence, restores the data array to the hard disk (now includes the total number of data points as the second row), and returns to the SET-UP PARAMETERS MENU. Note that the data file name is automatically incremented at this time, e.g., TEST.DT0 becomes TEST.DT1. In addition, in DA–HALL.BAS, you are asked whether or not to sort and/or interpolate the data according to temperature before restoring this data to the disk. Keep in mind that this step can be waived until a later time.

(C) P: Enters plot mode and plots the current data set on the computer screen.

(D) L: Enters list mode and lists the current data set on the computer screen.

(E) G: Redisplays the SCREEN GRAPHICS PARAMETERS MENU to allow you to change the plotting limits. However, adding a comparison set is not allowed at this time. Upon hitting a RETURN, the program execution continues in the plot mode. This feature is only available in DA–HALL.BAS.

Warning: do not spend too much time in this menu as the data collection is
temporarily suspended during this interruption.

(F) A: Toggles between "automatic $I_c$ mode" and "single $I_c$ mode." In the "automatic $I_c$ mode," the program continuously scans for $I_c$ values; this mode is used for obtaining $I_c$ as a function of temperature. In the "single $I_c$ mode," the program execution temporarily halts whenever $I_c$ is reached followed by a user prompt to enter a new starting current. This mode is used when obtaining the field dependence of $I_c$. More importantly, the data acquisition starts out in "single $I_c$ mode." In addition, this option only applies to DA–JCTH.BAS, and this interrupt feature is only possible when the program is currently executing.

(G) C: Toggles between high current mode ($I > 1 \text{ mA}$) and low current mode ($I < 10 \text{ mA}$). Prompts you to install a $1 \text{ k}$ resistor into the circuit as needed. This feature only applies to the DA–JCTH.BAS program.

(H) T: Halts program execution and prompts you to enter a new thermometer calibration file and a new scaling factor. As with the A and C interrupts, this feature only applies to the DA–JCTH.BAS program.

This concludes the operating principles of the data acquisition programs listed in the Appendix. For additional information, contact the author of this dissertation.
III. THEORETICAL BACKGROUND

A. Anderson–Kim Flux Creep Model

It is generally accepted that the critical current densities in the high-\(T_c\) superconductors are limited by flux creep in the Abrikosov flux lattice. Moreover, the Anderson–Kim flux creep model, discussed below, will be applied to the polycrystalline \(\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}\) thin films discussed later in the results. Thus, it is appropriate to include a brief overview of the development of the Anderson–Kim model. Prior to the 1960’s, Anderson did not take into account the interaction between the flux lines of the Abrikosov flux lattice; as a result, his first flux pinning theory predicted that the critical current density \(J_c\) was independent of the magnetic field \(H\), with\(^{49}\)

\[
J_c = \frac{c \ H_{cl}}{4\pi \ \ell} \ \frac{Lu(d/\xi)}{Lu(\lambda/\xi)}. \tag{6}
\]

Here \(d\) is the radius of the normal region of the fluxoid and \(\ell\) is the average spacing of the fluxoids. The other symbols in this equation are commonly used in present theories. In addition, \(H_{cl}\) is the lower critical field at which the Abrikosov flux lattice penetrates the superconductor, \(\xi\) is the superconducting coherence length, and \(\lambda\) is the penetration depth. However, Kim soon observed that \(J_c\) had a large field dependence that could only be overcome by introducing a flux "bundle" concept.\(^{49}\) In this revised theory, the critical current density was described by

\[
J_c = \frac{c \ \rho \ \ H_c(T)^2 \ \ d^2}{8\pi \ \ell \ B \ \lambda^2}. \tag{7}
\]
where \( \rho \) is the normal state resistivity extrapolated into the superconducting regime. Due to the weak temperature dependence of the thermodynamic critical field \( H_c(T) \) below \( T = 0.5 T_c \), \( J_c \) would be expected to be nearly independent of temperature at low temperatures, in contrast to the experimental observations. The key step in understanding the experimentally measured critical current densities occurred in 1962 when Anderson proposed that flux creep was initiated by a thermally activated process.\(^{49}\) More explicitly, a flux creep hopping rate proportional to \( e^{-\Delta W/kT} \) was proposed, where \( \Delta W \) is the barrier height assuming no external driving forces are applied. This had been previously neglected, since superconductivity occurred only at extremely low temperatures (\( T < 22K \)) for which thermally activated processes were difficult to envision.

The familiar flux creep equations,\(^{50}\) in the framework of the Anderson-Kim model, can be derived by considering a periodic potential well\(^{51}\) of depth \( U_0 \) and spacing \( x \) as shown in Figure 15(a). Let the flux bundles be trapped in these potential wells, hereafter called "pinning" centers. Also let \( x \) be the distance in which the bundles must be moved in order to be "depinned." The key equation\(^{49}\) is the definition of the "hop velocity,"

\[
v = x f_0 e^{-\Delta W/kT},
\]

(8)

where \( f_0 \) is the "attempt" frequency (phonon frequencies, \( \sim 10^{11} - 10^{13} \text{ s}^{-1} \)) and \( \Delta W = U_0 \) is the barrier height in the absence of external driving forces. An external flux gradient driving force (\( F_g \)) can be defined as a force density times a flux bundle volume.
Figure 15

(a) Periodic potential well of depth $U_0$ and spacing $x$ used to depict the magnetic flux "pinning" centers for the cases of (a) no external driving forces and (b) an externally applied driving force.
\[ F_L = \frac{B(\partial B/\partial x)}{4\pi} \quad V = \frac{J B}{c} \quad V , \quad (9) \]

where \( V \) is the flux bundle volume. For simplicity, consider only forward and backward hopping of the fluxoids along a line parallel to \( F_L \) [Figure 15(b)]. Thus, the net flux velocity is given by

\[ v = x f_0 \left[ e^{-(U_x-xF_x)/kT} - e^{-(U_x+xF_x)/kT} \right] , \quad (10) \]

where the first term represents forward motion and the second term represents backward motion. Simple trigonometric relationships allow us to write this as

\[ v = 2xf_0 e^{-U_x/kT} \sinh \left( \frac{J B V x}{c k T} \right) . \quad (11) \]

Moreover, the Lorentz equation allows us to write \( E = v B / c \). Also define the critical current density in the absence of flux creep as \( J_{c0} = c U_o(T,B) / B V x \) and a prefactor \( E_o = 2x f_0 B / c \) to obtain the familiar equations for the flux creep dissipative electric field at an applied current \( J \):

\[ E = E_o \ e^{-U_x/kT} \sinh \left( \frac{J}{J_{c0}} \frac{U_o}{kT} \right) , \quad (12) \]

where \( U_o \) is the "pinning" energy of the fluxoids, which depends on the applied magnetic field \( H \), temperature \( T \), and current density \( J \). Simple algebra allows one to express this in terms of an observed critical current density \( J_c \):

\[ J_c = J_{c0} \left( \frac{KT}{U_o} \right) \sinh^{-1} \left( \frac{E_c}{E_o} e^{U_x/kT} \right) , \quad (13) \]

where \( E_c \) is a measurement criterion, usually chosen as \( E_c \approx 1 \mu V/cm \). For
sufficiently strong pinning, the prefactor $J_{co}$ is assumed to be proportional to the theoretical depairing critical current density$^{50}$

$$J_d = \frac{c H_c(T)}{3\sqrt{6} \pi \lambda(T)}.$$

(14)

For large applied fields (e.g., for $H > B^*$, where $B^*$ is related to the field above which the flux lattice "melts"$^{52}$), we can define a flux creep "resistivity" in the limit $J \to 0$ as

$$\rho_{\text{creep}} = \frac{E}{J} = \frac{E_0}{J_{co}} \frac{U_0}{kT} e^{-U_{j<kT}} \approx e^{-U_{j<kT}}.$$  

(15)

By obtaining a systematic set of I–V curves taken at several applied fields $B$ and several temperatures $T$, this equation allows one to determine the functional form of the "pinning" energy. Zhu et al. performed this procedure on an epitaxial thin film of YBa$_2$Cu$_3$O$_7$ to obtain the following experimental expression for the "pinning" energy.$^{53}$

$$U_o(T,B,J) = U_{co} \left(1 - \frac{T}{T_c}\right)^{1.8} \left(1 - \frac{B}{B_c}\right) e^{-\frac{J}{J_{co}}}.$$  

(16)

Since this expression is not directly relevant to the measurements in this dissertation, readers interested in this expression are referred to Reference 53. Interestingly, a similar analysis was performed on two types of polycrystalline thin films of YBa$_2$Cu$_3$O$_7$ and these results are briefly discussed in Chapter VII.
B. The Hall Effect in Metals

1. Simple Metals: Single Parabolic Band

The Hall effect is defined as phenomenon that generates a potential difference between the edges of a strip of material carrying a longitudinal electric current when placed in an external magnetic field perpendicular to the direction of current. To better understand the significance of this effect, we must begin with the equation of motion for a particle of charge $q$ in an applied electromagnetic field (SI units):

$$F = q[E + (v \times B)] , \quad (17)$$

where $E$ is the electric field, $B$ is the magnetic field, and bold characters denote vector quantities. Recall that a simple metal can be represented by an electron gas in which the Fermi sphere encloses the occupied electron orbitals in $k$-space.\(^{54}\) If the external forces are balanced, the net momentum is zero so that for every occupied orbital $k$ there is a corresponding occupied orbital $-k$. Moreover, upon the application of an external force, assumed constant, for a time interval $t$, every orbital has its $k$ vector increased by $\delta k = \mathbf{F} t/\hbar$. This is equivalent to translating Fermi sphere by a displacement $\delta k$ as shown in Figure 16. In actual metals, we cannot neglect the impulses due to scattering. Such collisions can be represented by $\mathbf{F}_{\text{sc}} = \hbar \delta k/\tau$, where $\tau$ is the relaxation time. Thus, we can write

$$\hbar \left( \frac{d}{dt} + \frac{1}{\tau} \right) \delta k = F . \quad (18)$$

If $mv = \hbar \delta k$ and $B = B_z z$, the equations of motion become
Fermi sphere in the ground state of a free electron gas. Left segment (a) represents the possible k–orbitals under no externally applied forces, whereas the right segment (b) represents the shifting of the average momentum upon application of a driving force: \( N |F| t \), where \( N \) is the number of electrons and \( t \) is the time. \textit{Source:} C. Kittel, \textit{Introduction to Solid State Physics} (Wiley, New York, 1986).
\[ m \left( \frac{d}{dt} + \frac{1}{\tau} \right) v_x = q \left( E_x + B_z v_y \right), \]
\[ m \left( \frac{d}{dt} + \frac{1}{\tau} \right) v_y = q \left( E_y - B_z v_x \right); \]
\[ m \left( \frac{d}{dt} + \frac{1}{\tau} \right) v_z = q E_z. \]

(19)

The steady state solution is obtained by setting the time derivatives equal to zero. For convenience, assume the charge carriers are electrons, i.e., \( q = -e \), to obtain

\[ v_x = \frac{e\tau}{m} \left( E_x - \omega_c \tau v_y \right); \]
\[ v_y = \frac{e\tau}{m} \left( E_y + \omega_c \tau v_x \right); \]
\[ v_z = \frac{e\tau}{m} E_z. \]

(20)

These equations describe closed electron orbits having a cyclotron frequency of \( \omega_c = eB_z/m \). Moreover, taking \( |e| = 1.6 \times 10^{-19} \) C, \( m = m_e = 9.1 \times 10^{-31} \) kg, and \( B_z \) as our maximum attainable field of 8T, we see that the maximum cyclotron frequency that can be obtained with our cryostat is \( 1.4 \times 10^{12} \) s\(^{-1}\). Using the band structure value for the Fermi velocity in \( \text{YBa}_2\text{Cu}_3\text{O}_7 \), i.e., \( <v_F^2>^{1/2}_{ab} \approx 2.2 \times 10^7 \) cm/s\(^5\), the circumference of the cyclotron orbits can be calculated: \( S = 2\pi<v_F^2>^{1/2}_{ab}/\omega_c \approx 10,000\) Å \( > > \text{ mfp (~50Å)} \). Thus, complete orbits are never attained before being scattered (defined as the low-field limit), which is the basis for all the remaining calculations in this chapter. Readers interested in the high-field limit are referred to Hurd\(^{44}\).

The Hall field is the electric field developed perpendicular to both the current density \( j \) and the externally applied magnetic field \( B \). Define a coordinate system so
that the current is constrained to move along the x-axis, the magnetic field is applied along the z-axis, and the resulting Hall field is measured along the y-axis. From Equation (20), the only solution is given by

\[ E_y = -\omega_c^\tau E_x = -\frac{eB_z^\tau}{m} E_x . \]  

(21)

The Hall coefficient is defined (in the low-field limit\(^{56}\) by

\[ R_H = \frac{E_y}{j_x B_z} . \]  

(22)

The significance of this constant becomes apparent upon substitution of the electrical conductivity\(^{54}\) \( \sigma = j_x/E_x = n_H e^2\tau/m \) into Equation (21):

\[ R_H = -\frac{1}{n_H e} . \]  

(23)

Inspection of this important result reveals that the Hall coefficient offers a means in which one can determine the sign and concentration \( n_H \) of carriers in a material. Moreover, using a free electron model with \( N(E) \propto E^2 \), Pickett shows that a more instructive expression for \( R_H \) can be written as\(^{57}\)

\[ R_H = -\frac{3}{2e E_F N(E_F)} , \]  

(24)

where \( E_F \) is the Fermi energy and \( N(E_F) \) is the electronic density of states at the Fermi level. Also, the Hall coefficient \( R_H \) is negative for electrons and positive for holes. Note that the lower the Hall coefficient, the greater the carrier concentration. Although \( R_H \) is depicted in most experimental Hall plots, the Hall resistivity \( \rho_{xy} \) is
occasionally encountered. This quantity is simply defined by

$$\rho_{xy} = B_x R_H = \frac{E_y}{j_x} .$$  \hspace{1cm} (25)

In addition, another important quantity, known as the Hall angle, is defined as

$$\tan(\theta_H) = \frac{E_y}{E_x} = -\omega_c \tau = f(B,T)$$ \hspace{1cm} (26)

The Hall angle above, which can be obtained from Equation (21), is a relative measure of the relaxation time $\tau$. However, this quantity is field dependent due to the cyclotron frequency term and as a result, the field used to determine the Hall angle must be shown with the data. Unfortunately, the simple results [Equations (23)-(26)] derived in this section, although applicable to most simple metals, cannot be directly applied to YBa$_2$Cu$_3$O$_{7-\delta}$ materials, for at least three reasons. First, YBa$_2$Cu$_3$O$_7$ has four bands that cross the Fermi level requiring a more rigorous multi-band analysis of the Hall coefficient $R_H$. Second, the "collision" time $\tau$ changes across the various Fermi surfaces of this material. Finally, the simultaneous presence of both holes and electrons complicate the analysis. Therefore, the effects of multiple bands as well as the simultaneous presence of both electrons and holes on the Hall coefficient will be discussed in the succeeding sections.

2. Multiband Effects

Many metals have more than one band crossing the Fermi level; therefore, it is imperative to determine the effects of multiple bands on the observed Hall
coefficient $R_{ii}$ before attempting to interpret any Hall measurements. For simplicity, assume two isotropic bands cross the Fermi level so that we can take $R_{ii} = -1/n_{Hi}e$ for each band and neglect scattering between the bands.\textsuperscript{58} Later, the results will be generalized for any number of bands. The electric field for the first band is

$$E_1 = \frac{j_1}{\sigma_1} + \frac{q_1\tau_1}{m_1\sigma_1} (B \times j_1) ,$$  \hspace{1cm} (27)

where $\sigma_1$ is the conductivity of Band 1. Likewise, the electric field for the second band is

$$E_2 = \frac{j_2}{\sigma_2} + \frac{q_2\tau_2}{m_2\sigma_2} (B \times j_2) ,$$  \hspace{1cm} (28)

where $\sigma_2$ is the conductivity of Band 2. Since both bands occupy the same real space, all carriers experience the same electric field. Thus, the following two constraints are imposed:

$$E = E_1 = E_2 , \hspace{1cm} \text{and}$$  \hspace{1cm} (29)

$$j = j_1 + j_2 = \text{total current density} .$$  \hspace{1cm} (30)

Ziman\textsuperscript{59} solves these vector equations to obtain

$$j = \begin{bmatrix} \sigma_1 \left[ \frac{1 + q_1^2\tau_1^2B^2/m_1^2}{1 + q_1^2\tau_1^2B^2/m_1^2} \right] + \frac{\sigma_2}{1 + q_2^2\tau_2^2B^2/m_2^2} \end{bmatrix} E - \begin{bmatrix} \sigma_1 q_1 \tau_1 / m_1 \left[ \frac{1 - q_1^2\tau_1^2B^2/m_1^2}{1 + q_1^2\tau_1^2B^2/m_1^2} \right] \\ \sigma_2 q_2 \tau_2 / m_2 \left[ \frac{1 - q_2^2\tau_2^2B^2/m_2^2}{1 + q_2^2\tau_2^2B^2/m_2^2} \right] \end{bmatrix} (B \times E) .$$  \hspace{1cm} (31)

Expressing this equation in terms of $E$ as a function of $j$ and $B \times j$ leads to
\[ R_H = \frac{\sigma_1^2 R_{H1} + \sigma_2^2 R_{H2}}{\left(\sigma_1 + \sigma_2\right)^2} \]  \hspace{1cm} (32)

Furthermore, a more general result for the apparent Hall coefficient for any number of bands could be written as

\[ R_H = \sum_i R_{Hi} \left(\frac{\sigma_i}{\sigma}\right)^2 \]  \hspace{1cm} (33)

where \( R_{Hi} \) is the Hall coefficient of the \( i \)-th band, \( \sigma_i \) is the conductivity of the \( i \)-th band, and \( \sigma = \sigma_1 + \sigma_2 + \ldots \). Note that in a multiband system, with only one type of carrier, i.e., either electrons or holes, the minority carriers will usually not effect \( R_H \) noticeably. This follows since the observed Hall coefficient \( R_H \) is the average of the individual \( R_{Hi} \)'s associated with the separate bands, but weighted by the square of their conductivities. Thus, we are frequently justified in using the following equation for the dominant band: \(^{60}\)

\[ n_H^* = -\frac{1}{R_H e} \]  \hspace{1cm} (34)

However, if both electrons and holes are present, \( n^* \) can become very large even if small carrier densities occur in all bands (termed compensated metals\(^{44}\)). For instance, in a two band scenario containing one electron band and one hole band, Equations (32) and (34) simplify [see Figure 17] to give
Figure 17

\[
\hat{n}_H = \frac{\sigma^2}{e^4} \left[ \left| \frac{\tau_{el}}{m_{el}^2} \right|^2 - \left| \frac{\tau_{ho}}{m_{ho}^2} \right|^2 \right]^{-1}.
\]

(35)

Nevertheless, in any case, \(n_H^*\) tends to give an upper bound to the actual carrier density. Although not proven here, Ong generalized this statement to include any number of bands, in the 2D limit, where each Fermi surface could have any arbitrary shape.

Like the multi-band Hall coefficient, the multi-band Hall angle is a function of the relaxation time of all bands. This can be shown by combining Equations (22) and (33), while utilizing \(E_x = j_x/\sigma:\)

\[
\tan(\theta_H) = \frac{E_y}{E_x} = \frac{B_z}{\sigma} \sum_j R_{Hj} \sigma_j^2.
\]

(36)

Moreover, if each individual band is isotropic, e.g., can be described by \(R_{Hj} = -1/n_{Hje}\), this simplifies to a more instructive expression

\[
\tan(\theta_H) = -\frac{1}{\sigma} \sum_j \omega_j \tau_j \sigma_j.
\]

(37)

Therefore, the Hall angle is simply an average of the individual relaxation times weighted, not by the squares of the conductivities, but simply by the conductivities to the first power. The most important thing to note in a multi-band metal is that both the Hall coefficient and the Hall angle become functions of the carrier concentrations as well as the relaxation times.

Markiewicz\(^{62}\) first suggested that the anomalous temperature dependence of \(R_H\) observed in \(YBa_2Cu_3O_{7-\delta}\),\(^{63}\) e.g., \(R_H \propto 1/T\), could be due to the collective
effects of a hole band associated with the planes and an electron band associated with the chains. Eagles\textsuperscript{64} performed this analysis on the Hall data taken at full oxygenation ($\delta = 0$) in YBa$_2$Cu$_3$O$_{7-\delta}$. In order to obtain simultaneous fits to both the resistivity $\rho$ and the Hall coefficient $R_H$ as a function of temperature, it was determined that $n_{el}/n_{ho} \approx 1000$. In a similar fashion, the Hall data obtained for this dissertation were fit to this model at various oxygen contents across the 90K $T_c$ vs. $\delta$ plateau. The electron and hole densities were assumed constant with temperature. The resulting fits [Figure 18] require

$$\mu_{el} = \frac{e^2 \tau_{el}}{m_{el}} = (9.4 \times 10^{-24}) T^{-0.77} + (3 \times 10^{-26}) ;$$  \hspace{1cm} (38)

$$\mu_{ho} = \frac{e^2 \tau_{ho}}{m_{ho}} = (1.7 \times 10^{-21}) T^{-1} ,$$  \hspace{1cm} (39)

where $T$ is the temperature in Kelvins and $\mu$ is defined as the carrier mobility (given in S.I. units). This analysis of $R_H$ was restricted to oxygen deficiencies $\delta$ near the 90K plateau, since the carrier mobilities given above were assumed to be independent of $\delta$. In actuality, the carrier mobilities probably decrease before reaching the semiconducting phase, e.g., $\delta \rightarrow 0.6$. Interestingly, it is important to point out that the observed Hall coefficient remains positive simply due to the relative mobility ratio

$$\frac{\mu_{ho}}{\mu_{el}} = 180 T^{-0.25} + 3 .$$  \hspace{1cm} (40)

Therefore, the holes are more mobile than the electrons, and even though the electron
Fits of the transport properties to the simple two band model described in the text. (a) Resistivities taken across the 90K plateau (symbols) are fit to the model (curves). (b) Likewise, apparent Hall carrier densities fit to the same model. (c) The electron and hole density components as a function of oxygen deficiency δ required to obtain the fits above. Interestingly, each component carrier density extrapolate towards zero at the oxygen content for which $T_c$ approaches zero.
carrier density is higher, the Hall coefficient remains positive as a result. Unfortunately, as interesting as this analysis seems, the results are probably "fortuitous", since YBa$_2$Cu$_3$O$_{7-\delta}$ actually has four bands crossing the Fermi level. Moreover, in a simple two band scenario in which each band has a different effective mass $m_i$ or a different relaxation time $\tau_i$, the application of a magnetic field would attempt to produce different deflections to each carrier, which is not allowed, since all carriers are subjected to the same electric fields. Resulting forces would undoubtedly lead to large magnetoresistances due the redistribution of the current between the two bands,$^{59}$ and such effects are not observed in YBa$_2$Cu$_3$O$_7$. In the band structure of YBa$_2$Cu$_3$O$_7$, two of the four bands are predominately "hole like" in character, whereas the remaining two are both "hole like" and "electron like" in character.$^{55}$ Finally, each band has a differing degree of dimensionality that complicates the meaning the Hall coefficient. As a result, a Bloch–Boltzmann approach must be utilized before we can understand the behavior of the Hall coefficient.


The Boltzmann equation governs the macroscopic transport properties of all materials.$^{59}$ Also known as the transport equation, this equation simply states that the local concentration of carriers in the state $\mathbf{k}$ in the vicinity of a point $\mathbf{r}$ in space does not change with time. Like most theories, in order to calculate the transport properties from this equation, careful approximations must be made. This is necessary, since a rigorous solution of this equation requires knowledge of the scattering operator, which
is difficult to calculate, especially for the layered cuprate perovskites that have complex structures.\textsuperscript{55} Nevertheless, the variational principle\textsuperscript{65} can be used to make reasonable approximations, and as it turns out, many of the transport properties, including the Hall coefficient, do not depend on the scattering mechanism to a first level of approximation. However, due to the excessive and tedious algebra involved in these derivations, which is described in more detail elsewhere,\textsuperscript{66} only an outline of the derivation of the transport properties will be discussed, with an emphasis on the physics.

The first derivation of the transport coefficients, e.g., conductivity $\sigma$ and Hall tensor $R_H$, from the Boltzmann equation was performed by Jones \textit{et al.}\textsuperscript{67} This solution is now considered standard, and detailed accounts can be found in at least two common texts.\textsuperscript{44,65} Therefore, only an outline of this procedure is considered here. First, assume that an electronic relaxation time $\tau$ exists and it is a function of $k$ (this assumption is only valid in the low-field limit). Consider only the isothermal case so that the Boltzmann equation in the presence of both an electric field $E$ and a magnetic field $B$ can be written as\textsuperscript{68}

\begin{equation}
\frac{e}{h} \left[ E + v \times B \right] \cdot \nabla_k F(k) = \frac{F(k) - f(k)}{\tau(k)} ,
\end{equation}

where $F(k)$ is the mean number of carriers in the state $k$ having an energy $\epsilon(k)$, and $f(k)$ is the mean number of carriers before the application of the fields. To solve this equation, set

\begin{equation}
F = f + g(v) ,
\end{equation}

where $g(v)$ is the deviation from equilibrium upon applying the external fields. Placing
Equation (42) into Equation (41), while neglecting higher order terms having products of $E$ and $g(\nu)$, gives the result

$$
\left[ 1 + \frac{e}{\hbar^2} \left( \nabla_k e \times B \cdot \nabla_k \right) \right] g(\nu) = -\frac{\tau(k)e}{\hbar} \cdot \nabla_k e \left( \frac{\partial f}{\partial \epsilon(k)} \right),
$$

(43)

where $-\partial f/\partial \epsilon(k)$ is the derivative of the Fermi–Dirac distribution with respect to energy $\epsilon$. For small $B$, this can be solved by an iterative procedure that gives

$$
g(\nu) = \sum_{n=0}^{\infty} \left( -\frac{\tau(k)e}{\hbar^2} \nabla_k e \cdot B \cdot \nabla_k \right)^n \left( -\frac{\tau(k)e}{\hbar} E \cdot \nabla_k e \frac{\partial f}{\partial \epsilon(k)} \right).
$$

(44)

Before establishing the physical meaning of each term in this series, we first need to calculate the net electric current density $j$ due to the perturbed distribution $F(k)$:

$$
j = -\frac{e}{\Omega_o} \sum_k \nu(k) F(k) = \frac{e}{\hbar \Omega_o} \sum_k \nabla_k e \cdot g(\nu),
$$

(45)

where $\Omega_o$ is a normalization volume, which is inversely proportional to the density of states in $k$–space. Moreover, the equilibrium distribution has been omitted, since it makes no net contribution to the current density $j$. Placing Equation (44) into Equation (45) leads to the following series expansion for $j$, where each term represents a summation and a particular galvanomagnetic coefficient:

$$
j = -\left( \frac{e}{\Omega_o} \right) \sum_k \nu \tau(k)e(E \cdot \nu) \frac{\partial f}{\partial \epsilon(k)} + \left( \frac{e}{\Omega_o} \right) \sum_k e_{ij} \nu \frac{\tau(k)^2 e^2}{\hbar^2} \nu_a E \cdot \left( \frac{\partial^2 \epsilon(k)}{\partial k_i \partial k_j} \right) H_y \left( \frac{\partial f}{\partial \epsilon(k)} \right) \cdots,
$$

(46)

where $\epsilon_{ijk}$ is the totally antisymmetric tensor (equal to +1 for even permutations of the
indices, -1 for odd permutations, and 0 if two indices are equal). To identify the physical meaning of each term in this series, we can compare the following Taylor expansion for the current density, valid for small \( B \), obtained from the theory of irreversible thermodynamics,\(^{69}\) in a term by term manner to Equation (46):

\[
j_{\alpha} = \sigma_{\alpha\beta} E_{\beta} + \sigma_{\alpha\beta\gamma} E_{\beta} B_{\gamma} + \sigma_{\alpha\beta\gamma\delta} E_{\beta} B_{\gamma} B_{\delta} + \cdots = -\left( \frac{e}{\Omega_o} \right) \sum_k \nu_{\alpha}(k) F(k), \tag{47}
\]

where the sums over repeated indices are understood. Direct comparisons allow us to now obtain explicit formulas for the standard transport coefficients:

\[
\sigma_{\alpha\beta} = \varepsilon^2 \left( \frac{\tau n}{m} \right)_{\alpha\beta} = \left( \frac{e^2}{\Omega_o} \right) \sum_k \tau(k) \nu_{\alpha}(k) \nu_{\beta}(k) \left[ -\frac{\partial f}{\partial e(k)} \right]; \tag{48}
\]

\[
\sigma_{\alpha\beta\gamma} = -\frac{\varepsilon^3}{\hbar \Omega_o} \sum_k \tau(k) \nu_{\alpha}(k) \left[ \nu(k) \times \nabla_{\kappa} \right]_{\gamma} \nu_{\beta}(k) \left[ -\frac{\partial f}{\partial e(k)} \right]. \tag{49}
\]

Moreover, the Hall tensor is defined as\(^{57}\)

\[
R^H_{yz} = \frac{E_y}{j_z B_z} = \frac{\sigma_{yx}}{\sigma_{xx} \sigma_{yy}}. \tag{50}
\]

In these expressions, \( \Omega_o \) is our normalization volume, whereas \(-\partial f/\partial e\) is the Fermi-Dirac function. Unfortunately, most materials, including the high-\( T_c \) cuprates, require long and tedious calculations to obtain the transport coefficients from these equations. Thus, only the evaluated, three independent components of the Hall tensor and the temperature dependence of the resistivity, obtained elsewhere,\(^{55}\) will be shown for \( \text{YBa}_2\text{Cu}_3\text{O}_7 \). For now, the only important thing to note from these equations is that the assumption of an isotropic scattering rate \( 1/\tau \) leads to a Hall tensor that is
independent of $1/\tau$. Such an assumption, along with the replacement of $-\partial l/\partial \epsilon$ by $\delta(e-e_F)$, leads to a temperature independent Hall coefficient $R_H$, since all other variables are independent of temperature.

Before further discussion of the anomalous temperature dependence observed in $R_H$, a brief diversion into the temperature dependence of the resistivity $\rho$ will be presented in the framework of the isotropic scattering approximation. In a more general sense, the steady state distribution of electrons at an arbitrary point $r$ in the presence of an electric field $E$, magnetic field $B$, and thermal gradient $\nabla T$ is given by the functional form\textsuperscript{55}

$$F(k,r) = \frac{f \left[ T - \tau v(k) \cdot \nabla T ; e(k - F_{\text{ext}} \tau / \hbar) \right]}{1 + \exp \left( \frac{e - \mu}{k_B T} \right)}, \tag{51}$$

where $e(k)$ is the energy, $v(k)$ is the group velocity $\partial e/\partial (\hbar k)$ of an electron with quantum numbers $(k, \text{band n, spin } \sigma)$, and the denominator contains the Fermi–Dirac distribution. The physical meaning of Equation (51) can be stated more simply as the number of electrons in the state $k$ at point $r$ is the same as the number occurring at equilibrium, except that an external force shifts the momentum by an amount $F_{\text{ext}} \tau$, since the previous collision, and the temperature shifts by the amount $-\tau v_k \cdot \nabla T$. In addition, the external force can be written

$$F_{\text{ext}} = -eE - ev(k + eE \tau / \hbar) \times B. \tag{52}$$

Note that these equations are simply a more elaborate means of depicting the increase of the average momentum of the "Fermi sphere." The only free parameter in
Equation (51) is the relaxation time \( \tau \); it is argued in the variational approach\textsuperscript{65} that \( \tau \) should be chosen in a manner to maximize the current for a particular scattering operator. Assuming the only scattering mechanism is electron-phonon, then this approach applied to a metal in the limit \( T < \Theta_D \), was shown by Allen\textsuperscript{66} to yield a relaxation time

\[
\frac{\hbar}{\tau_{el-ph}} = 4\pi k_B T \int_0^{\omega_{max}} \frac{d\omega}{\omega} \alpha_{tr}^2 F(\omega) \left[ \frac{\hbar \omega / 2k_B T}{\sinh(\hbar \omega / 2k_B T)} \right]^2,
\]  

(53)

where \( \alpha_{tr}^2 F(\omega) \) is the electron-phonon spectral function and \( \omega_{max} \) is the maximum phonon frequency. Unfortunately, \( \alpha_{tr}^2 F(\omega) \) is not known for any of the cuprates; however, inelastic neutron scattering was previously used to measure \( G(\omega) \), which is \( F(\omega) \) weighted by the neutron-phonon matrix elements rather than the electron-phonon matrix elements.\textsuperscript{57} These spectral functions should be quite similar, since the electron-phonon interaction is expected to be dominated by the Cu and O atoms as with the neutron cross sections.Remarkably, Allen et al.\textsuperscript{55} show that this relaxation time, calculated using the function \( G(\omega) \), instead of \( F(\omega) \), gives a resistivity curve of the form

\[ \rho = \rho_0 + mT \]  

[Figure 19(a)], which agrees well with experimental findings. Therefore, the temperature dependence of the resistivity in YBa\(_2\)Cu\(_3\)O\(_7\) appear to be consistent with an electron-phonon scattering mechanism.

Returning to the Hall effect discussions, Allen et al. calculated the three independent Hall tensor components for fully oxygenated YBa\(_2\)Cu\(_3\)O\(_7\) [Figure 19(b)] utilizing the transport equations, their band structure results, and the Onsager relations \( \sigma_{yxz} = -\sigma_{xyz} \).\textsuperscript{55} As with the resistivity predictions, the magnitude of
Figure 19

(a) 

(b) 

Calculated electrical transport properties of YBa$_2$Cu$_3$O$_7$ assuming electron-phonon scattering mechanisms dominate. (a) Temperature dependence of the resistivity due to the Fermi-surface carriers. (b) The three elements of the Hall tensor calculated as a function of energy near $E_F$. These values agree with the experimental results for this dissertation. Sources: P. B. Allen, W. E. Pickett, and H. Krakauer, Phys. Rev. B 37, 7482 (1988) and W. E. Pickett, Rev. Mod. Phys. 61, 433 (1989).
the Hall tensor components agree very well with the experimental findings. However, the assumption of a constant scattering rate, as well as the replacement of the Fermi–Dirac function with the one occurring at absolute temperature, leads to a failure in explaining the source of the anomalous temperature dependence of \( R_H \). This failure motivated Ong\(^1\) to develop an unique interpretation of the Boltzmann equation in terms of the basal plane anisotropy of the "scattering path length" vector \( \Delta l/l_{av} \), in order to address the temperature dependence of \( R_H \), which is discussed in the next section.

4. Geometric Interpretation of the Hall Conductivity

In the low-field limit, the Hall tensor components are known to be very sensitive to the local curvature of the Fermi surface (FS).\(^7\) Moreover, many materials have very complex FS shapes making it difficult to explain the experimentally measured Hall data in context with the band structure predictions. On the other hand, Ong\(^6\) developed an unique interpretation of Hall conductivity, e.g., Equation (49), for the class of materials having two-dimensional Fermi surfaces. More explicitly, it is argued that the low-field limit Hall conductivity is proportional to the number of flux quanta \( \phi_o \) threading the I-curve, where the I-curve is defined as the "scattering path length" vector \( l(k) = v_{\mathbf{k}} \tau_{\mathbf{k}} \), as \( \mathbf{k} \) traces out the FS. Furthermore, it will be shown that if the anisotropy of this "scattering path length" vector, denoted by \( \Delta l/l_{av} \), changes with temperature, a temperature dependent Hall coefficient results.

This new interpretation of the Hall conductivity will be discussed starting with the standard transport coefficients. Taking the magnetic field \( \mathbf{B} \parallel -\mathbf{z} \), and the electric
field $E \parallel x$, Equation (49) can be rewritten:

$$
\sigma_{xy} = \frac{2e^3B}{h} \sum_k \left( -\frac{\partial f}{\partial \epsilon(k)} \right) (v \cdot \tau_x)(v \times B) \cdot \nabla(v \cdot \tau_x).
$$

(54)

For a 2D system, assuming $kT < \epsilon_F$, this can be written as an integral evaluated around the FS curve

$$
\sigma_{xy}^{2D} = \frac{e^3}{2\pi^2h} \oint \frac{dk}{|v|} [v \cdot \tau_x(v \times B) \cdot \nabla(v \cdot \tau_x)],
$$

(55)

where $|v|^{-1}$ is the density of states factor, and $k_i$ is the component of $k$ taken along $t$ (tangential unit vector to the FS curve). Furthermore, $v \times B/|v| = Bt$, which allows the integral to be written as

$$
B \oint dk_t (t \cdot \nabla I_t)I_y = BA_t,
$$

(56)

where

$$
A_t = \frac{B}{B} \cdot t \cdot \oint dl x \frac{l}{2}.
$$

(57)

$A_t$ denotes the "Stokes" area swept out by the vector $l(k)$ as $k$ moves around the FS.61

Substituting Equations (56) and (57) into Equation (55) leads to the important result

$$
\sigma_{xy}^{2D} = \frac{e^2}{h} \left( \frac{A_t}{\pi l_s^2} \right) = 2 \frac{e^2}{h} \left( \frac{\phi}{\phi_0} \right),
$$

(58)

where $l_s = (\hbar/eB)^{1/2}$ is defined as a magnetic length, $\phi_0 = \hbar/e$ is the flux quantum, and $\phi = BA_t$ is the magnetic flux threading the $I$-curve. Recall that this is only the numerator of the Hall coefficient defined by Equation (50). In order to visualize how these findings might lead to a temperature dependent Hall coefficient, consider only
crystals having N-fold symmetries in the xy-plane. In this case, Ong argues\textsuperscript{61} that the in-plane conductivities can be written as scalars. More explicitly, for 2D systems, Ziman shows that the diagonal conductivities can be derived from Equation (48),\textsuperscript{65}

\[ \sigma_{xx} = \left( \frac{e^2}{h} \right) \int \, ds \, l_k \cos^2 \theta_k , \quad (59) \]

where the integration is taken over the FS, and \( \theta_k \) is the angle between the unit vector \( x \) and \( l(k) \). Assuming N-fold symmetry exists (\( N > 2 \)),\textsuperscript{71} the FS can be divided into \( N \) identical wedges, which may be mapped onto each other by rotations, where the angle \( \theta_k \) is changed to \( (\theta_k + 2\pi m/N) \) on the \( m \)-th wedge. Thus, Equation (59) can be written as

\[ \frac{\sigma_{xx}}{e^2/h} = \frac{1}{\pi} \int_{A s - s i n} ds \sum_{m=1}^{N} \cos^2(\theta_k + 2\pi m/N) . \quad (60) \]

Standard math handbooks equate the summation term to \( N/2 \), and furthermore, using the relationship\textsuperscript{61} \( l_{av}S = N \int \, ds \, l_k \), one obtains

\[ \frac{\sigma_{xx}}{e^2/h} = \frac{\sigma_{yy}}{e^2/h} = \frac{l_{av}S}{2\pi} , \quad (61) \]

where

\[ l_{av} = \oint \, ds \frac{l_k}{S} . \quad (62) \]

Again this integral is taken over the whole FS, where \( S \) is the FS circumference, and \( l_{av} \) is the average of \( l_k \). Finally, upon placing Equations (58) and (61) into Equation (50), we obtain the simple relationship for the temperature dependence for the Hall coefficient:
where $\Delta l/l_{av}$ is highly correlated to the "anisotropy" of the "scattering path length" vector in the xy-plane. Hence, $\Delta l/l_{av}$ is termed the anisotropy. Therefore, in the conventional Bloch-Boltzmann theory, the Hall coefficient $R_H$ in 2D systems becomes temperature dependent only if $\Delta l/l_{av}$ changes with temperature. Furthermore, this result can be generalized, in a complicated fashion, to include 3D systems as well as multiband effects (readers interested in these cases are referred to Ref. 61), but, these cases are not discussed here because of the 2D nature of the layered cuprate perovskites.

However, if electron-phonon scattering dominates, the temperature dependence of $\Delta l/l_{av}$ should display three distinct regimes of differing behavior determined by $\Theta_D$.\textsuperscript{61} At very low T, impurity scattering, which tends to have an isotropic-I, dominates the transport properties leading to a constant $R_H$ with T. Unfortunately, this regime is out of reach in the high-$T_c$ superconductors. At mid-range temperatures ($\sim 0.2 T_D$), phonon scattering is highly anisotropic leading to a temperature dependent $R_H$ in many materials. Third and most importantly, at high T ($\geq T_D$), the scattering by phonons tends to be isotropic, so that the isotropic $\tau$ assumption is valid.\textsuperscript{72} Furthermore, this should lead to a saturation of $R_H$ above $T_D$ ($\sim 440 K$ in YBa$_2$Cu$_3$O$_7$). Interestingly, Fiory et al. have measured $R_H$ up to 600K ($\gg T_D$) in YBa$_2$Cu$_3$O$_7$, and find no evidence for such saturation.\textsuperscript{73} Therefore, even though the resistivity vs. temperature follows the expected behavior for electron-phonon scattering,
the Hall coefficient is apparently dominated by a nonphononic mechanism, which is probably electronic in origin.

5. Unconventional Hall Effect Theories

Due to considerable regularities occurring in the normal state properties of \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) (e.g., universal inverse Hall angles \( \theta_H^{-1} = AT^2 + B \) upon doping with various impurities\(^74\)), led Anderson to suggest that \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) behaved as a two-dimensional Luttinger liquid.\(^75\) Although presently in an early stage of development and not generally accepted, Anderson argues that most transport properties, including the conductivity, can be represented by correlation functions derived in the framework of a bosonized form of a one-dimensional Hubbard model such as that given by Haldane:\(^76\)

\[
\mathcal{H} = \sum_\Omega \sum_\Omega \hbar k_F(\Omega) \left[ \nu_s(\Omega)Qb^*_{s\Omega}b_{s\Omega} + \nu_c(\Omega)Qb^*_{c\Omega}b_{c\Omega} \right], \tag{64}
\]

where the \( b \)'s are bosonized representations of the charge and spin fluctuations. Moreover, it is argued that this Hamiltonian can be interpreted in terms of two kinds of solitons: spinons, which behave as electrons with spin and no charge with a momentum \( k_F \) located at an angle \( +\Omega \); and holons, which carry the charge with a momentum \( 2k_F \) located at an angle \( -\Omega \). In addition, the two are connected in the sense that when the holons move one way, the spinons moves in the opposite. Thus, in a Luttinger liquid, charge and spin separate.\(^75\)

Separation of charge and spin should lead to interesting behavior in the normal
state properties. For example, Anderson argues that upon application of an electric field, the holons are accelerated causing a backflow of the spinons, giving rise to a resistivity proportional to the number of thermally excited spinons, i.e., \( \rho \propto kT \).\(^{75}\) In contrast, an entirely different situation arises in the presence of a magnetic field. The equation of motion in a magnetic field is

\[
\frac{\hbar}{\tau} \frac{\partial k}{\partial t} = e \left( \frac{\nabla e_k}{\nabla k} \times \mathbf{B} \right) - \frac{\hbar}{\tau} \frac{\partial k}{\partial t},
\]

(65)

where \( \tau \) denotes the apparent relaxation time measured in the presence of a magnetic field. This equation of motion is argued to represent an acceleration of the spinons parallel to the Fermi surface, without disturbing the holon occupancies.\(^{75}\) As a result, the spinons can only interact with other spinons or magnetic impurities. Being a fermion–fermion interaction, we are left with the well known \( T^2 \) behavior for the temperature dependence of the inverse Hall angle. Therefore, the different temperature dependencies for the resistivity and inverse Hall angle, e.g., \( T \) and \( T^2 \), respectively, lead to the observed temperature dependence of the Hall coefficient \( R_H \propto 1/T \).

Although the two-dimensional Luttinger liquid theory accurately describes the anomalous temperature dependent Hall coefficient \( R_H \) for YBa\(_2\)Cu\(_3\)O\(_{7-\delta}\), this theory is far from being proved and generally accepted. On the other hand, Markiewicz recently provided an explanation for a weaker, but somewhat similar, temperature dependent Hall coefficient observed in La\(_{2-x}\)Sr\(_x\)CuO\(_4\) (LSCO).\(^{77}\) In this material, the 2D CuO\(_2\) band is assumed to be nested while sitting near a peak in the 2D electronic density of states. In this model it is shown that the conductivity is given by
\[ \sigma_{xx} = \left[ P(T) + xQ(T) \right] \frac{ne^2}{m} \]  

where \( P \) is the probability that the electrons are scattered into a particular \( \text{CuO}_2 \) branch and \( Q = 1 - P \) is the probability that the electrons are scattered into the remaining branches. Moreover, \( x \) is the hole doping away from half filling of the 2D \( \text{CuO}_2 \) band and \( n \) is the carrier density. Finally, this model predicts the following Hall coefficient:

\[ R_H = \frac{x}{[P(T) + xQ(T)]^2 ne} \]

Here the temperature dependence of \( R_H \) arises from the temperature dependence of the scattering probabilities \( P \) and \( Q \). However, it is argued that the stronger temperature dependence of \( R_H \) in \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) is probably due to another mechanism. Although possible, this proposed scattering mechanism is unlikely in \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) since, \( P \) and \( Q \) are unlikely to be strongly temperature dependent. In addition, multiband effects probably occur in \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) which are neglected in this model.

C. \( H_{c2} \) Determined from Fluctuations

The studies of fluctuation effects in superconductors have recently been revived due to the discovery of the high-\( T_c \) materials. In this dissertation research, the recent fluctuation theory of Ullah and Dorsey,\(^{21}\) in the limit of large magnetic fields, was utilized to deduce the \( H_{c2} \) slopes for \( H \parallel c \). The fluctuation theory was developed in the framework of the Lawrence-Doniach model,\(^{78}\) which accounts for the layered structure of the high-\( T_c \) materials. This theory gives the following set of equations for
the fluctuation conductivities for both the 3D and 2D scaling:

$$\left(\frac{H}{T}\right)^{1/2} \sigma_{yy}^{2D} = g \left[ A \frac{T - T_c(H)}{(TH)^{1/2}} \right]$$ \hspace{1cm} (68)

$$\left(\frac{H^{1/3}}{T^{2/3}}\right) \sigma_{yy}^{3D} = g \left[ A \frac{T - T_c(H)}{(TH)^{2/3}} \right]$$ \hspace{1cm} (69)

$$(TH)^{1/2} \sigma_{zz}^{2D} = f \left[ A \frac{T - T_c(H)}{(TH)^{1/2}} \right]$$ \hspace{1cm} (70)

$$\sigma_{zz}^{3D} = f \left[ A \frac{T - T_c(H)}{(TH)^{2/3}} \right].$$ \hspace{1cm} (71)

In these equations, $\sigma_{ii}$ is the fluctuation conductivity along the $i$-th crystal axis (i.e., $\sigma_{yy}$ denotes $ab$-plane while $\sigma_{zz}$ denotes $c$-plane), $H$ is the applied magnetic field along the $c$-axis, $T_c(H)$ is the mean field transition temperature, which is field dependent. The scaling functions $g$ and $f$ should be the same for all fields, and the constant $A$ is independent of the temperature and field. The only free parameter is $T_c(H)$ which, selected carefully, leads to the $H_{c2}$ slope. This is accomplished by simply plotting each side of the equation of interest, while neglecting the functions $g$, $f$, and $A$, along different axis, while selecting the $T_c(H)$ for each magnetic field transition to generate a universal curve. Interestingly, the best choices of $T_c(H)$ usually lead to linear $H_{c2}$ slopes near $T_c$, as expected.\(^7\) By inspection, Equations (68) and (69) apply to the $c$-oriented epitaxial films used in this dissertation, whereas Equations (70) and (71) could be applied to any untwinned $a$-oriented films, if ever developed.
IV. CORRELATIONS BETWEEN $R_H$, $T_c$, AND $J_c$

A. Overview of Most Important Experimental Results

Before discussing in detail each of the experimental results, a brief overview of the important principal findings will be presented. The electrical transport properties of YBa$_2$Cu$_3$O$_{7-\delta}$ vary systematically with increasing oxygen deficiency $\delta$. Both the resistivity $\rho(\delta)$ and the Hall coefficient $R_H(\delta)$ increased with $\delta$ at similar rates, and consequently the Hall angle, given by $\tan(\theta_H) = R_H B/\rho$, changes only slightly. In all films, the critical current densities $J_c(\delta,H=0)$ measured in self-field extrapolated towards zero for compositions near the edge of the 90K plateau, while the temperature and field dependencies of $J_c/J_c(H=0)$ remained fixed for $\delta < 0.15$, both of which are suggestive of geometrical effects. For larger oxygen deficiencies ($\delta > 0.3$), the field dependencies of $J_c(\delta,H)$ were similar to those observed in polycrystalline YBa$_2$Cu$_3$O$_7$ and the superconducting Hall effect transitions exhibited systematic "noise", indicative of granular-like behavior. Pinning energies determined both from the field dependence of $J_c/J_c(H=0)$ and from in-field resistive transitions show plateau-like behavior near full oxygenation even though $J_c$ decreases rapidly in this region. On the 90K plateau, most films showed no broadening in the resistive transitions; however, all films showed some broadening in the transitions between the 90K and 60K plateaus. Films post-annealed at low-PO$_2$ usually showed "peaked" $T_c$ behaviors with $\delta$, unlike the high-PO$_2$ post-annealed films which typically show "flat" 90K plateaus. However, the Hall coefficients were found not to rely on the processing conditions, suggesting that
differences in the measurable carrier densities are not responsible for these different $T_c(\delta)$ patterns.

B. Discussion of Results

1. Effect of Oxygen Deficiency $\delta$ on the Resistivity and Hall Coefficient

The removal of oxygen from YBa$_2$Cu$_3$O$_{7-\delta}$ leads to a progressive increase in the resistivity [Figure 20(a)] as well as a decrease in Hall number [Figure 20(b)]. These observations suggest steady decreases in the density of states, which according to simple BCS theory should lead to steady decreases in $T_c$. In actuality, two plateaus are observed in $T_c$ vs. $\delta$ which could be reconciled either by phase separation$^{18,20}$ or by some complex electronic mechanism.$^{13,14}$

Interestingly, the insets of these figures show the effects of room temperature annealing which may be ascribed to the formation of oxygen-ordered "Ortho-II" phase at fixed $\delta \geq 0.4$. These room temperature ordering effects were studied at three estimated oxygen contents of 6.35, 6.40, and 6.45. For investigation at each of these fixed oxygen contents, the sample was quenched from 200°C, rapidly mounted, and cooled below 250K in about 3 minutes. No ordering effects were ever observed during measurements at $T < 250K$, and the final results are depicted by the dashed curves in Figure 20(a) and Figure 20(b). After completion of each data acquisition sequence, the sample was warmed to room temperature, and allowed to "age" until the resistivity reached a minimum saturation—approximately four days at each oxygen content [Figure 21]. These results are depicted by solid curves in the same figures.
Resistivity (a), Inverse Hall coefficient (b), and Inverse Hall angle (c) for a laser ablated film of YBa$_2$Cu$_3$O$_{7-\delta}$ as a function of temperature and oxygen deficiency $\delta$. Insets show the apparent changes in the "Ortho-II" phase with room temperature annealing. The dashed curves in parts (a) and (b) represent the behavior immediately after quenching from 200°C, whereas the corresponding solid curves represent the behavior after aging for four days. The Inverse Hall angle is shown on a log-log plot to depict the relative insensitivity of the $T^2$ behavior to oxygen deficiency.
Figure 20 (continued)
The effect of room temperature annealing on the resistance in the "Ortho-II" phase $\text{YBa}_2\text{Cu}_3\text{O}_{\sim 6.5}$. This data were obtained at a temperature of 297K and at an estimated oxygen content of $7-\delta \approx 6.40$. Note that four days were required to reach saturation. Similar plots were obtained at the oxygen contents 6.35 and 6.45. The solid curve is a guide to the eye.
In addition to an observed reduction in resistivity, this ordering-related annealing always led to an increase of the observed Hall number, which could be interpreted as an indication of additional charge carriers being transferred to the Cu–O₂ planes as suggested by the electronic model first proposed by Veal. However, this observation does not rule out a phase separation scenario, since a parallel configuration of two dissimilar conductors (denoted by indexes 1 and 2) will yield an observed Hall coefficient \( R_H \) given by,

\[
R_H = \frac{R_2 R_{H1} + R_1 R_{H2}}{R_1 + R_2}
\]  

(72)

where \( R_{H1} \) and \( R_1 \) refer to the Hall coefficient and the resistance contributed by the \( i \)-th conductor, respectively. It is clear from this equation that the phase contributing the least electrical resistance would average more heavily in the apparent Hall coefficient. Moreover, if phase separation leads to a larger proportion of the "better" phase, i.e., lesser resistivity and higher oxygen content, the apparent value of \( R_H \) would decrease with room temperature annealing. This would occur because the aging process would create a larger proportion (i.e., less resistance) of the phase having the smaller value of \( R_H \) [see Figure 20(b)]. Therefore, the normal state resistivity and normal state Hall coefficient results alone cannot determine whether or not phase separation occurs in oxygen deficient \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \).

Another feature of Figure 20(a), which is observed in all samples, is a slight broadening of the resistive transitions off the 90K plateau. It is unlikely that this broadening results from the formation during cool down of layers with differing oxygen
contents, since no 90K onsets are observed for compositions off the 90K plateau [see Figure 20(a)]. Rather, this broadening off the 90K plateau is most likely due to a $T_c$ distribution, with a series connection of domains with different $T_c$'s.

A potentially important finding is the relative constancy of the Hall angle $\tan(\theta_H) = E_y/E_x = R_{Hi}B/\rho$ for oxygen deficiencies $\delta$ when $\delta \leq 0.5$ [Figure 20(c)]. In a multiband system, the Hall angle can be derived from simple expressions for a multiband system $^5^\text{9}$

$$
\tan(\theta_H) = \frac{E_y}{E_x} = \frac{B_z}{\sigma} \sum_i R_{mi} \sigma_i^2.
$$

(73)

Assuming each (parabolic) band can be described by the expressions $R_{Hi} = -1/n_i e$ and conductivity $\sigma_i = n_i e^2 \tau_i / m_i$, this becomes

$$
\tan(\theta_H) = -\frac{1}{\sigma} \sum_i \omega_i \tau_i \sigma_i.
$$

(74)

Here $\omega_i = eB/m_i$ and $\tau_i$ are the cyclotron frequencies and relaxation times for the $i$-th band, respectively. Moreover, the band structure calculations predict four bands crossing the Fermi level in YBa$_2$Cu$_3$O$_{7-x}$, and each of these bands is expected to have different effective masses. $^7$ Therefore, it is plausible that upon oxygen depletion, the individual conductivities would change at different rates. Under these circumstances, Equation (74) suggests that significant deviations should occur in the observed magnitude and temperature dependence of the Hall angle with changing oxygen deficiency. On the contrary, the Hall angle changes only slightly over most of the oxygen content range [Figure 20(c)] and this suggests that one band dominates the
normal state properties with fields $H \parallel c$. On the other hand, for large oxygen deficiencies ($\delta > 0.5$), deviations occur in the temperature dependence of the Hall angle [Figure 20(c)]. In addition, these deviations correspond with onsets of magnetoresistance [Figure 22] supporting the existence of multiband effects only for the compositions of $\delta$ in excess of $\delta > 0.5$.\textsuperscript{59}

2. Temperature Dependence of the Hall Coefficient

To understand the temperature dependence of the Hall coefficient, one can use the proposal that YBa$_2$Cu$_3$O$_7$ behaves as a two-dimensional Luttinger liquid.\textsuperscript{75} Use of this single band theory is justified by and consistent with the arguments just presented. In this formalism, the observed Hall angle $\tan(\theta_H)$ depends on a "transverse" relaxation rate $\tau$ as $\cot(\theta_H) = (\omega_c \tau)^{-1} = A T^2 + (\omega_c \tau_{imp})^{-1}$. Here $\omega_c$ is the field dependent cyclotron frequency and $1/\tau_{imp}$ is the scattering rate due to impurities. In a Luttinger liquid, separation occurs between the charge and spin quasiparticles. Furthermore, application of a magnetic field leads to the rotation of $k$ space allowing the "transverse" relaxation rate to include only the effects of the spin-spin interactions. Being fermions, these interactions should lead to the well established $T^2$ scattering process in $\cot(\theta_H)$, whereas the impurity scattering term only includes the effects of magnetic scattering centers. Referring to the log-log plot [Figure 20(c)], the inverse Hall angle indeed varies as $T^2$ over a wide range of oxygen deficiencies ($\delta \leq 0.55$) in YBa$_2$Cu$_3$O$_{7-\delta}$. On the other hand, a "transport" relaxation rate $\tau_{tr}$ is measured in the resistivity and is proportional to the decay rate of the accelerated electrons into elementary excitations.
Magnetoresistance \( \Delta \rho / \rho(0) \) observed in YBa\(_2\)Cu\(_3\)O\(_{7-\delta}\) for oxygen deficiencies in excess of \( \delta > 0.5 \). These data were obtained as a function of temperature and at an applied field of 8 Tesla. Note that "aging" effects associated with the ordering in the "Ortho-II" phase were observed at the composition 7-\(\delta = 6.40\). The onset of magnetoresistance corresponds with the same composition at which the inverse Hall angle deviates from its \( T^2 \) behavior. These observations are consistent with multiband effects when \( \delta > 0.5 \).\(^{59}\)
(holons and spinons), such that

\[ \rho \propto \frac{m}{ne^2} \left( \frac{1}{\tau_r} + \frac{1}{\tau_{\text{imp}}} \right) \]  \hspace{1cm} (75)

where \( \tau_{\text{tr}}^{-1} \propto T \). In relatively clean materials, the impurity scattering rate \( 1/\tau_{\text{imp}} \) may be neglected. Combining these results, one has \( 1/(R_{\text{He}}) \propto \cot(\theta_{\text{He}})/\rho \propto nT \), where \( n \) is the density of charge carriers and \( e \) is the electron charge. Thus, within the Luttinger liquid approach, the average slopes of the inverse Hall coefficient curves, which vary almost linearly with temperature [Figure 20(b)], serve as a relevant electronic parameter for displaying our data. In Figure 23 are plotted the transition temperatures \( T_c(R=0) \) and \( T_c(\text{mid}) \) as well as the critical current densities in self-field \( J_c(\delta, H=0) \), as a function of \( d(1/R_{\text{He}})/dT \). Note that a simpler plot of superconducting properties, e.g., \( T_c \) and \( J_c \), as a function of \( 1/(R_{\text{He}}) \) would give qualitatively similar results [see Figure 20(b)]; however, the function \( 1/(R_{\text{He}}) \) must be chosen at an arbitrarily fixed temperature when displaying data in this fashion. Overall, most superconducting properties improve with increasing \( d(1/R_{\text{He}})/dT \).

Although this behavior is consistent with the Luttinger liquid model, alternate explanations for the temperature dependence of \( 1/(R_{\text{He}}) \) may be found in a sharp peak in the electronic density of states (DOS) lying near the Fermi surface.\(^{77,81}\) The existence of such a van Hove singularity (vHs) is suggested in the band structure;\(^{7,82}\) however, band structure calculations place the DOS peak \( \sim 0.1 \) eV below the Fermi energy. According to Pickett,\(^{57}\) this DOS peak is associated with the chain layer derived bands, which are more difficult to determine accurately than the plane related
Transition temperature $T_c$, and critical current density $J_c$ evaluated at fixed reduced temperatures, as a function of either the oxygen deficiency $\delta$ or the "apparent carrier density" from the Luttinger Liquid Theory described in the text. Notice that $J_c$ extrapolates toward zero at the edge of the 90K plateau, suggestive of phase separation. The solid (dashed) curves were obtained from a laser ablated (BaF$_2$ processed) film. Extrapolations do not occur at exactly the same point due to uncertainties in the film thickness.
bands. Interestingly, these same chain related bands in the 60K phase, YBa$_2$Cu$_3$O$_{6.5}$, lie farther below the Fermi surface, according to Yu. In this picture, the systematic decrease in the temperature dependence of $R_H$ with $\delta$ merely reflects a steady displacement of the peaked DOS ($\nu$Hs) from the Fermi energy. But, to be plausible, this scenario requires that the peak is actually nearer to the Fermi surface than calculated.

Yet another possible explanation comes from Bloch-Boltzmann theory. These calculations, however, are complicated and the Fermi-Dirac distribution $-\partial f/\partial e$ must often be approximated by $\delta(\varepsilon-\varepsilon_F)$. Moreover, the standard approximation of isotropic scattering leads$^{55}$ to a temperature-independent $R_H$. As described in Section III.4, Ong$^{61}$ has shown that, in the framework of this conventional theory, a temperature dependent $R_H$ can result from a changing anisotropy of the ab-plane "scattering path length" vector $l(k) = v_k \tau_k$ with temperature $T$. Nevertheless, these latter mechanisms may prove difficult in explaining the universal quadratic temperature dependence of the inverse Hall angle, $\cot(\theta_H) = AT^2 + B$ [Figure 20(c)]. Finally, this quadratic temperature dependence is also reported well above the Debye temperature$^{73}$ which tends to support a nonphononic scattering mechanism.

3. Effect of Oxygen Deficiency $\delta$ on the Critical Current Density

This section considers the transport critical current density $J_c$, measured in self-field. Examination of Figure 23 shows that $J_c$ extrapolates toward zero at an oxygen deficiency near the edge of the 90K plateau. This feature was observed in all films,
and somewhat similar behavior was reported earlier by Ossandon et al. in magnetic measurements of current density in bulk, aligned \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \). For \( \delta \leq 0.15 \), \( J_c \) varies linearly with \( \delta \). In this regime, the functional dependencies of \( J_c \) on temperature and field [Figure 24] are constant, which suggests a geometrical decrease in the amount of 90K phase. In this view, \( J_c(\delta) \) deviates from its linear decrease with \( \delta \) for compositions \( \delta \geq 0.15 \) because other, lower \( J_c \) phases then conduct appreciable portions of the supercurrent. This tapering occurs near the same oxygen content at which the field dependencies of \( J_c \) begin to degrade. This degradation implies reductions in the pinning energy, as discussed in the next section.

4. Determination of the Pinning Energy

Several methods provide means of determining the pinning energy. These include analyses of I–V curves, resistive transitions \( \rho(T,H) \), or dependencies of critical currents \( J_c(T,H) \) on field. Recently, self consistent values for the pinning energies were obtained in fully oxygenated \( \text{YBa}_2\text{Cu}_3\text{O}_7 \) epitaxial films determined from the I–V curves and from in-field resistive transitions. However, if phase separation occurs in oxygen deficient \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \), the I–V curves would clearly be difficult to interpret, since the actual current path dimensions, which are required to calculate the flux creep resistivities, would be unknown. Similarly, Arrhenius plots of the resistive transitions would be expected to broaden (theoretically shown by others) as a result of inhomogeneities. For example, the apparent \( T_c \) distributions observed in the Hall transitions in Figure 25 would probably lead to errors in the derived pinning energies.
Reduced critical current densities as a function of temperature (a), applied field for $H \parallel c$ (b), and applied field for $H \parallel ab$ (c) for various oxygen contents. No apparent changes in pinning energy occur while on the 90K plateau even though $J_c(0)$ decreases rapidly [see Figure 23]. Interestingly, many of the curves in (a) behave as SNS proximity tunneling (solid curves) off the 90K plateau. The dashed curve is a representative polycrystalline sample which indicates the granular like behavior when $\delta > 0.2$. 
Figure 24 (continued)

\[ \frac{J_c}{J_c(0)} \]

\( T = 0.85 T_c \)

\( H \parallel ab \)

90K Plateau

Off Plateau

\( H \) (kOe)
Figure 25

Superconducting Hall effect transitions obtained at 8 Tesla for various oxygen contents. All Hall transitions with δ ≥ 0.3 show reproducible "onsets" indicative of a distribution of T_c's. However, these "onsets" were never observed on the 90K plateau nor in any resistive transition as shown in the inset.
Note also that, on the 90K plateau, $J_e$ decreases by roughly an order of magnitude while the conductivity decreases by a factor of only 1.8. As a result, the derived pinning energies obtained under relatively high electric fields, i.e., resistive transitions, may be in error due to induced normal currents in the lower $T_c$ phases which are forced normal by the applied magnetic fields.

To develop this more rigorously, consider the standard expression for the creep resistivity:

$$\rho = \frac{E_o}{J_{c_0}} \frac{U_o(T,B)}{kT} \exp \left(-\frac{U_o(T,B)}{kT}\right), \quad (76)$$

which is valid in the limit of small current and thus is applicable to the resistive transition measurements. Here $J_{c_0}$ is the critical current density in the absence of flux creep, $E_o$ is proportional to the elementary "attempt" frequency, and $U_o$ is the activation energy for flux creep. Due to the weak, logarithmic sensitivity of the analysis, the prefactor is generally approximated to be constant. It follows that the slopes of the Arrhenius plots of $\ln \rho$ vs. $1/T$ are equal to $-U_o(T,B)/k$. The situation becomes more complex in the phase separation scenario. Using the resistor combination equations

$$\rho^{\pm_1} = \sum_{i}^{n} f_i \rho_i^{\pm_1}, \quad (77)$$

where $f_i$ denotes the volume fraction of the $i$-th phase, and $+/-$ specifies series/parallel combinations, respectively, the Arrhenius equation becomes

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\[ \ln \rho = \ln \left[ \frac{E_o}{J_{co}} \frac{U_o(T,B)}{kT} \right] + \ln \left[ \sum_s f_s \exp \left( \frac{-U_o(T,B)}{kT} \right) + \sum_n f_n (\alpha T)^{z_1} \right]. \] (78)

The \( s/n \) indices represent superconducting/normal metal phases, respectively, and \( \alpha \) represents the relative scaling between the flux creep and normal state resistivities, i.e.,

\[ \alpha \propto \left[ \frac{k J_{co}}{E_o U_o(T,B)} \right] \rho_{onset}. \] (79)

In a percolative model, with parallel conduction channels dominating the resistive behavior, Equation (79) shows the factor \( \alpha \) approaches zero as \( J_c \) extrapolates to zero near the edge of the 90K plateau. It follows that the normal metal term cannot be ignored in the determination of \( U_o(T,B) \) from the Arrhenius plots. Otherwise, the pinning energies obtained from the analysis would be in error. Equation (78) was used to fit the resistive transitions of a film grown by the BaF\(_2\) process\(^{41}\) [Figure 26 inset] at various oxygen deficiencies \( \delta \), assuming a parallel combination of one superconducting phase with one normal metal conduction channel. (Note that the normal metal term could be ascribed to the collection of lower \( T_c \), oxygen deficient phases, which are forced normal in the temperature range of the resistive transitions).

The ratio of the normal state resistivity to the flux creep resistivity at full oxygenation was assumed to be on the order of \( \alpha \approx 10-100 \), and was allowed to decrease with increasing oxygen deficiency according to Equation (79). This analysis yields a plateau in the pinning energy \( U_o \) [Figure 26] as a function of \( \delta \) near full oxygenation, even though \( J_c \) decreases in this region. In addition, a curious peak in \( U_o \) was obtained on the 60K plateau, possibly reflecting enhanced superconducting properties in the long
Figure 26

Pinning energy $U_\infty(\delta) = U_\delta(\delta,T=0,B=1T)$ (open symbols) and $T_c(\delta)$ (solid circles) as a function of oxygen content $7-\delta$ for a film prepared by the BaF$_2$ process. The open circles represent $U_\infty(\delta)$ as determined from fitting Equation (78) to the Arrhenius curves at various oxygen deficiencies. The inset depicts an actual fit at $\delta = 0$. The open squares (triangles) are $U_\infty \propto B^2$ for $H \parallel c$ ($H \parallel ab$) as defined by Equation (80). The values of $U_\infty(\delta)$ for $H \parallel ab$ are scaled by a factor of 1/5 for clarity.
range ordered "Ortho-II" phase near \( \delta = 0.5 \). This peak also coincided with an increase in the critical current density \( J_c \) observed in this same film. Therefore, uncertainties still remain regarding the behavior of \( J_c \) and \( U_o \) in the region of the 60K plateau. Interestingly, the width of the \( U_o(\delta) \) plateau varies depending upon the method used to determine \( U_o \) [Figure 26]. Hence, it is plausible that the resistive transition model above is oversimplified in assuming the presence of only two distinct phases. Thus, unlike the case of fully oxygenated \( \text{YBa}_2\text{Cu}_3\text{O}_7 \), these plots do not appear to be a reliable means of determining the subtle behavior of \( U_o(T,B) \) in oxygen deficient \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \).

The most reliable method for determining the pinning energy is an analysis of the magnetic field dependencies of the critical current densities. This technique is unique in that knowledge of the bridge cross section is not required. Hettinger et al.\(^{87} \) showed that the field dependence of \( J_c/J_c(H=0) \) [see Figure 24(b)] could be described by the single parameter specifying the field at which the pinning force density extrapolates linearly to zero [Figure 27],

\[
B^* = \frac{U_o B}{kT} \ln \left( \frac{E_o}{2E_c} \right).
\]

This analysis assumes that \( U_o \propto 1/B \) as experimentally observed\(^{53,87} \) and that the denominator is roughly constant. The apparent degradation seen in \( J_c(\delta,H//c) \) for \( \delta \geq 0.15 \), as well as in \( J_c(\delta,H//ab) \) for \( \delta \geq 0.20 \), is clearly attributed to a decrease in \( U_o \) [Figure 26]. This probably leads to the progressive suppression of the \( J_c(\delta,T) \) curves observed at higher temperatures [Figure 24(a)]. The normalized flux pinning
Normalized pinning force density $F_p$ taken at 77K as a function of (a) $B$ and (b) $B/B^*$ as described in the text, both on and off the 90K plateau. The universal $F_p$ curve observed on the 90K plateau suggests the field dependence of the pinning energy given by $U_0 \propto 1/B$ is fixed across the plateau. However, off the plateau, the relative $B$ dependence may change, as in the polycrystalline films, leading to the observed shift in $F_{p,\text{max}}$. 
force density at various oxygen contents both on and off the 90K plateau are depicted in Figure 27. Off the 90K plateau, decreases in the relative strength of the $B$ dependence in $U_0$, similar to that found in polycrystalline films, may occur as a result of the films developing a "granular" like $J_c(H)$ for large oxygen deficiencies.

5. Constraints Imposed on Electronic Models

If the phase separation scenario does not apply, the initial decreases of $J_c (\delta \leq 0.15)$ could only be due to decreases in $J_{co}$ since, the flux creep pinning energy $U_0$ is constant in this regime. Recall that $J_{co}$ is defined as the critical current density in the absence of flux creep and is often assumed to be proportional to the depairing critical current density. As a result, this assumption leads to the proportionality $J_{co} \propto H_c^2 \xi_{ab}^2$. Moreover, others generally argue that $U_0$ should scale as $H_c^2 \xi^3/8\pi$ in a point pinning model, where $H_c$ is the thermodynamic critical field and $\xi$ is the superconducting coherence length. In the highly anisotropic cuprates, one has $\xi^3 = \xi_{ab}^2 \xi_c$ so that the constraint imposed by a constant $U_0$ becomes

$$H_c^2 \propto \frac{1}{\xi_{ab}^2 \xi_c^2}.$$  \hspace{1cm} (81)

From magnetization studies, Ossandon et al. concluded that the thermodynamic critical field $H_c$ rapidly decreases with increasing oxygen deficiency. However, if the phase separation scenario applies, these apparent decreases in $H_c$ could be due to a
decreasing volume fraction of the 90K phase with increasing $\delta$. Equation (81) implies a significant increase in the coherence length $\xi$ with increasing oxygen deficiency $\delta$, which should be reflected as a decrease in the upper critical field, since $H_{c2} = \phi_0/2\pi\xi^2$. Unfortunately, conclusive systematics of $H_{c2}$ vs. $\delta$ do not yet exist. The fluctuation analysis described in the next chapter indicates the existence of an $H_{c2}$ plateau while a Hao-Clem$^{92}$ analysis of magnetic measurements$^{83}$ show a steadily decreasing $H_{c2}(\delta)$. Thus, further information of the dependence of $H_{c2}$ with $\delta$ would be very useful.

6. "Peaked" $T_c(\delta)$ Behavior

Until now, the "peaked" $T_c(\delta)$ behavior (i.e., a maximum in $T_c$ at $\delta \neq 0$) has not been addressed, which is most apparent in epitaxial films initially grown under low oxygen partial pressures.$^{80,93}$ This maximum in $T_c$ is demonstrated midway on the 90K plateaus in $T_c$ vs. $\delta$ depicted in Figure 23 and Figure 26. Feenstra$^{94}$ has shown that these $T_c$ peaks occur with systematic values of oxygen deficiency $\delta$ depending on the initial growth conditions. This implies that the location of these peaks on the 90K plateau occur as a consequence of the level of cation "doping" introduced by the growth process. However, other mechanisms could be argued, including morphology differences or simply strains between the different phases, which are well established to have different c-lattice parameters. The latter argument appears possible since no significant splitting was observed in any of the x-ray diffraction peaks for the films studied [Figure 28(a) and Figure 28(b)]. However, keep in mind that one generally
High resolution x-ray diffraction scans of the (005) peak for (a) the laser ablated thin film at $7-\delta \approx 7.00$ and (b) the coevaporated thin film at $7-\delta \approx 6.90$. The low angle tail occurring near full oxygenation in the laser ablated film supports the existence of oxygen deficient regions. However, such tails were not observed in the oxygen deficient coevaporated films, even though the $J_c(\delta)$ behavior with $\delta$ was identical. Adapted from J. D. Budai (unpublished).
speaks in terms of large "doping" levels for the high-\(T_c\) superconductors, i.e., involving tens of percent of the unit cells, which probably alter the phonon properties as well as the electronic properties. McMillan previously showed that the coupling constant is affected by the phonon frequency spectrum.\(^{50}\) Thus, in the framework of an electron-phonon pairing mechanism,\(^{50}\) a more intuitive argument for these \(T_c(\delta)\) peaks could simply be stated as the "optimization" of the coupling constant \(\lambda = VN(E_F)\). In the coupling constant, \(V\) represents the matrix element of the electron-phonon interaction, while \(N(E_F)\) is the electronic density of states at the Fermi energy \(E_F\). Since knowledge of the phonon properties and band structure are limited, no definite conclusions on the behavior of \(\lambda\) as a function of "doping" can be drawn at the present. However, Figure 29 illustrates the Hall coefficients for two sets of films, grown from identical precursor-batches, by the BaF\(_2\) process,\(^{41}\) and post-annealed under different conditions. The data show that the apparent carrier densities do not depend upon the initial growth conditions. The differences between films of different precursors could stem either from slight compositional differences or simply from uncertainties in the film thickness. Overall, this result implies that the processing conditions have little or no effect on the electronic structure in the fully oxygenated state. Finally, recent evidence by others suggests that lattice instabilities, and not electronic mechanisms, are indeed responsible for the limiting transition temperature of \(\sim 90K\) observed in \(\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}\).\(^{95}\)
Inverse Hall coefficients taken on two sets of films with identical precursors but post-annealed under different conditions. The data suggest that growth conditions do not influence the overall carrier density. The slight differences between film batches may be attributed to small compositional differences in constituents or simply to errors in determining film thicknesses.
7. Brief Conclusion

In sum, the critical current densities $J_c$ were observed to decrease linearly with $\delta$, while extrapolating toward zero near the edge of the 90K $T_c(\delta)$ plateau. Over most of this regime, no changes were observed in the pinning energies $U_0$ and the upper critical fields $H_{c2}$ (discussed in the next chapter). These findings support the "extrinsic" phase separation/percolation mechanism giving rise to these $T_c(\delta)$ plateaus. On the other hand, the strong correlation between the Hall coefficient $R_H$ and the superconducting performance (i.e., $T_c$ and $J_c$) is believed to be an "intrinsic" property which supports a charge transfer from the "chains" to the "planes." Finally, I believe that the width of the $T_c(\delta)$ plateaus reflect the domain sizes of these separated phases.
V. UPPER CRITICAL FIELD \( H_{c2} \) ANALYSIS

A. Experimental Results

In the previous chapter, it was argued that an "\( H_{c2} \) plateau" vs. oxygen deficiency \( \delta \) supported a phase separation/percolation scenario occurring on the 90K \( T_c(\delta) \) plateau. (The **upper critical field** \( H_{c2} \) is defined as the magnetic field required to destroy superconductivity). Thus, knowledge of this \( H_{c2} \) behavior with the oxygen deficiency \( \delta \) was required. To determine this \( H_{c2}(\delta) \) behavior, the Ullah-Dorsey fluctuation theory\(^{21}\) was applied to the experimental data on two epitaxial \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) thin films grown by the \( \text{BaF}_2 \) process.\(^{41}\) The results (valid in the limit of large magnetic fields) support the existence of such a plateau in \( H_{c2} \). More explicitly, an \( H_{c2} \) slope of \(-1.7 \text{ T/K} \) near \( T_c \) was obtained for all oxygen stoichiometries in the range \( 6.8 \leq 7-\delta \leq 7.0 \). In addition, this oxygen range corresponded to the complete range of the 90K plateau in both films. In Figure 30, the determination of the \( H_{c2}(T) \) slope near \( T_c \) is depicted by a two step process based on Equation (69) [see Chapter III for details]. In order to obtain \( dH_{c2}/dT \), the fluctuation conductivity \( \sigma_f \) \((= \sigma_{ii}^{3D,2D}) \) must first be determined by extrapolating the normal state resistivity into the superconducting fluctuation regime followed by the application of

\[
\sigma_f = \sigma_{\text{total}} - \frac{1}{\rho_o + mT},
\]

where \( \sigma_f \) is the fluctuation conductivity, \( \sigma_{\text{total}} \) is the observed conductivity, \( \rho_o \) and \( m \) are the constants describing the linear extrapolation of the normal state resistivity into
Step by step determination of $-dH_{c2}/dT$ by utilization of the 3D scaling of the fluctuation theory. (a) First, the fluctuation conductivity $\sigma_f$ is determined as a function of temperature and applied field. These are plotted according to Equation (69) both on (b) and off (c) the 90K plateau. The only adjustable parameters are the mean field transition temperatures $T_c(H)$, which give $T_c$ as a function of $H_{c2}$, and these are chosen in such a way as to generate the universal curve shown. The resistive transitions obtained off the 90K $T_c$ vs. $\delta$ plateau are not adequately described by the fluctuation theory.
Figure 30 (continued)

(c) Off 90K Plateau

\[ \sigma_f H^{1/3}/T^{2/3} \]

\[ (T-T_c(H))/(TH)^{2/3} \]

- 1 T
- 4 T
- 8 T
the fluctuation regime. Due to the linearity of resistivity curves in temperature over a significant range of temperature in the normal state for both films, it was not necessary to obtain a quadratic fit. Second, these were in turn used in Figure 30(b) utilizing the 3D scaling behavior. The resulting \( H_{c2} \) curves were obtained by choosing \( T_c(H) \) for each applied field in order to obtain a universal curve. For oxygen contents in the regime of the 90K plateau, the best convergence always occurred by application of the 3D scaling [Equation (69)] assuming a linear \( H_{c2} \) vs. \( T \) with a slope of \(-1.7 \) T/K near \( T_c \). Interestingly, the temperature dependence of \( H_{c2} \) in both films extrapolated to zero at the mid point of the self-field resistive transitions. In contrast, the 2D scaling did not accurately describe the fluctuations; moreover, this scaling also suggested unacceptably low \( H_{c2} \) slopes, e.g., \(-1.2 \) T/K near \( T_c \). Off the 90K plateau, however, neither the 3D nor the 2D fluctuation equations accurately described the fluctuation regime of the in-field resistive transitions. For instance, the best fit possible at an oxygen content of \( 7-\delta \approx 6.7 \) was obtained by application of the 3D scaling and choosing an \( H_{c2} \) slope of about \(-2 \) T/K. These resulting curves [Figure 30(c)] clearly show differences in curvatures at each applied field. In addition, the convergence of these curves became worse as the oxygen content was further reduced.

For oxygen contents off the 90K plateau (typically \( \delta \geq 0.2 \)), the resistive transitions taken in self-field for both samples were observed to be broadened. Figure 31 shows typical Hall transitions taken off the plateau as well as the field dependence of \( J_c \) taken with \( H \parallel c \).\(^{38}\) Both plots indicate granular-like behavior at reduced oxygen contents in the range \( \delta \geq 0.3 \). It is possible that this "granularity" is
Evidence of granular-like behavior at reduced oxygen contents in YBa$_2$Cu$_3$O$_{7-\delta}$.
(a) Systematic "peaks" always appear in the Hall effect transitions whenever $\delta \geq 0.3$. These "peaks" suggest a $T_c$ distribution and never appear in the resistive transitions (see inset). (b) The field dependencies of the critical current density $J_c/J_c(H=0)$ behave more similarly to the polycrystalline materials (dashed curve) when $\delta \geq 0.3$. 

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responsible for an extrinsic broadening of the resistive transitions taken off the 90K plateau. As a result, the fluctuation theory cannot be applied, since this broadening of the transitions is apparently the result of several mechanisms in addition to those of fluctuations.

The $H_{c2}$ slopes determined by three different techniques are summarized in Figure 32. This figure compares the fluctuation results to the magnetization results of Ossandon et al. In the magnetization measurements, application of the Welp et al. analysis was found to give an initial $H_{c2}$ plateau of about $-2.1$ T/K with increasing oxygen deficiency $\delta$, whereas a recent Hao et al. analysis of the same data yielded a similar plateau, but with a smaller $H_{c2}$ slope of $-1.8$ T/K. Interestingly, the Hao et al. analysis of the magnetization data agrees reasonably well with the fluctuation analysis with respect to the range of the 90K plateau. More explicitly, the magnetization studies yielded a 90K plateau that spanned over a smaller range of $\delta$, e.g., $-6.89 - 7.00$. This range suggests an $H_{c2}$ plateau that occurs over most of the 90K plateau. Thus, an $H_{c2}$ plateau probably occurs over part of the 90K plateau. Regardless of any conflicting results, a plateau in $H_{c2}(\delta)$ is expected over the entire 90K $T_c$ vs. $\delta$ plateau and is discussed in the framework of BCS theory in Section C.

B. Phase Separation Effects

Evidence supportive of phase separation, i.e., chain site oxygen clustering, in oxygen deficient $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ was presented in the previous chapter. In addition, others have also argued that this phenomenon occurs in these materials.16,17,18,20

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Summary of the $H_c^2(T)$ slopes as a function of oxygen deficiency $\delta$ in YBa$_2$Cu$_3$O$_{7-\delta}$ determined by the in-field fluctuation analysis of epitaxial thin films (filled circles). These are compared to the magnetization results of bulk, aligned YBa$_2$Cu$_3$O$_{7-\delta}$ adapted from J. G. Ossandon et al., Phys. Rev. B 45, 12534 (1992). (open symbols).
Furthermore, such occurrences of phase separation may be directly responsible for the 90K and 60K plateaus observed in $T_c$ vs. $\delta$ via geometrical effects and the percolation of current as discussed earlier.\textsuperscript{38} In the phase separation scenario, the actual current path dimensions are unknown except at full oxygenation; as a result, deviations probably occur between the observed $H_{c2}$ slopes and the actual $H_{c2}$ slopes due to cross sectional errors in the determination of the fluctuation conductivities. Testing this hypothesis, a rigorous analysis was conducted to determine the probable effects of phase separation on the "apparent" $H_{c2}$ values as determined from the above fluctuation theory. In a simple model, it was assumed that oxygen deficient YBa$_2$Cu$_3$O$_{7-\delta}$ simply separated into regions of 90K and 85K "phases." Two sets of in-field resistive transitions were experimentally obtained—one at full oxygenation with $T_c = 90$K and the other just off the 90K plateau with $T_c = 85$K. The former set had an apparent $dH_{c2}/dT$ of $-1.7$ T/K near $T_c$, while the latter had an apparent $dH_{c2}/dT$ of $-2.0$ T/K near $T_c$. Both parallel and series combinations of these two sets of resistive transitions were calculated as a function of temperature using $R = R_{90K} + R_{85K}$ for the series combinations and $1/R = 1/R_{90K} + 1/R_{85K}$ for the parallel combinations. The resulting resistive transitions were then analyzed in the framework of the fluctuation theory utilizing the 3D scaling. The resulting "apparent" $-dH_{c2}/dT$'s as a function of the volume percentage of the 90K phase [Figure 33] indicate that the fluctuation analysis is sensitive only to the presence of the 90K phase in a parallel conduction system. This important result indicates that errors in the bridge dimensions do not lead to errors in the $H_{c2}$ values as determined from the fluctuation analysis. In contrast, series
Predicted effect of phase separation on the "apparent" $H_{c2}$ slopes as derived from the fluctuation analysis. The model used to generate these results assumed that phase separation occurs between regions of $T_c = 90K$ and $T_c = 85K$. Parallel conduction phases should have little or no effect on the "apparent" $H_{c2}$, whereas series phases should lead to significant increases in the "apparent" $H_{c2}$ values above a certain threshold amount of the minority phase (arrow). The inset indicates the appearance of the self-field resistive transitions for the left and right extremes of the main graph for series phases.
combinations of phases generate false increases in \(-dH_{c2}/dT\). For instance, a mere 0.3% of the 85K phase in series with the 90K phase should lead to some error in the determined \(H_{c2}\) even though such series combinations would have little effect on the overall resistivity [see Figure 33 inset]. Moreover, in this analysis, if the 85K phase exceeds \(\sim 2\%\) of the total volume fraction, the resistive transitions are found to be poorly described by the fluctuation theory, and such results are similar to the experimental results taken off the 90K plateau [Figure 30(c)]. In light of these results, the \(H_{c2}\) slopes of \(-1.7\) T/K taken across the 90K plateau are believed to be unaffected by any phase separation effects, while the failure of the fluctuation theory off the 90K plateau is believed to reflect the presence of gross oxygen inhomogeneities.

**C. Implications for BCS Theory**

Unfortunately, universal results for \(H_{c2}(H\parallel c)\) as a function of oxygen deficiency \(\delta\) in \(YBa_2Cu_3O_{7-\delta}\) cannot be deduced from the various experimental determinations of \(H_{c2}\) summarized in Figure 32. However, a plateau in \(H_{c2}\) vs. \(\delta\) probably exists over part of the 90K plateau in \(T_c\) vs. \(\delta\). Nevertheless, the importance of an \(H_{c2}\) plateau as a function of \(\delta\) will be stressed here in the framework of simple BCS relationships. More explicitly, if \(H_{c2}\) changes with \(\delta\) while on the 90K plateau, either changes must occur in the Fermi velocity or another pairing mechanism other than electron-phonon mediation would be responsible for superconductivity, assuming \(T_c\) is indeed limited by an electronic mechanism. Recall from the clean limit of BCS theory (Note: the latter equation is in the range of strong coupling and was adapted
from recent measurements of the energy gap

\[ H_{c2}(0) = \frac{\Phi_0 \pi \Delta^2(0)}{2 \hbar^2 v_F^2}, \text{ where} \]  \hspace{1cm} (83)

\[ \Delta(0) = \frac{(6-8)}{2} k T_c. \]  \hspace{1cm} (84)

In the above equations, \( \Phi_0 \) is the flux quantum \( 2.07 \times 10^{-7} \) gauss-cm\(^2\), \( \Delta(0) \) is the superconducting energy gap at the Fermi surface at absolute zero, \( v_F \) is the Fermi velocity of the superconducting charge carriers, and \( T_c \) is the superconducting transition temperature. Combining Equations (83) and (84) leads to the simple proportionality

\[ H_{c2}(0) \propto \frac{T_c^2}{v_F^2}. \]  \hspace{1cm} (85)

Superconductivity is generally believed to be associated with the CuO\(_2\) planes, and Yu\(^9\) has shown that the plane related pieces of the Fermi surface are virtually identical between the YBa\(_2\)Cu\(_3\)O\(_7\) and YBa\(_2\)Cu\(_3\)O\(_6.5\) structures, suggesting that the Fermi velocity is relatively insensitive to changes in the oxygen deficiency \( \delta \). Finally, Equation (85) leads one to expect a plateau in the upper critical field \( H_{c2} \) as a direct consequence of the 90K \( T_c \) vs. \( \delta \) plateau.

Finally, Allen et al. gives \( \langle v_x, y \rangle^2 \rangle^{1/2} = 2.3 \times 10^7 \) cm/s based on band structure calculations,\(^{55}\) that implies \( H_{c2} \approx 35 \) kOe, which is over one order of magnitude below the accepted value of \( H_{c2}.^{98} \) This discrepancy may be resolved by either an uncertainty in the prefactor of Equation (84) or by a non-BCS type pairing mechanism.
that determines $T_c$. Moreover, recent evidence suggests that the maximum transition
temperature of 92K in YBa$_2$Cu$_3$O$_{7-\delta}$ is limited by a phase instability,$^9$ which could
explain this $H_{c2}$ discrepancy in addition to the enhanced values for the prefactors in
Equation (84) observed by others.$^9$ In sum, the "apparent" $H_{c2}$ plateau in $\delta$ does not
rule out a BCS type pairing mechanism in the YBa$_2$Cu$_3$O$_{7-\delta}$ system.
VI. HALL EFFECT TRANSITIONS

A. Evidence for Percolation in the Transitions

Further evidence for percolation in YBa$_2$Cu$_{3}$O$_{7-\delta}$ occurs in the superconducting Hall effect transitions. Indirect evidence for shifting current paths (i.e., percolation) with changing temperature is presented in Figure 34. This plot represents a typical derivation of the Hall coefficient for fully oxygenated YBa$_2$Cu$_2$O$_7$. In all of the thin films studied, the Hall "offset" (the average of the two opposing Hall "signals") never behaved as a simple scaled down resistivity versus temperature curve. Moreover, random peculiarities [see Figure 34] in these "offsets" existed in the superconducting transitions of each sample. If the current simply flowed longitudinally along the bridge without any percolation, these "offsets" should simply reflect the physical misalignment of the Hall probes. In contrast, no such behavior was ever observed, even at full oxygenation, indicating that the current paths probably change with temperature. Finally, such physical shifts with temperature can easily account for the unusual "offsets" of the Hall "signals."

In addition, systematic changes were observed in the superconducting Hall effect transitions as the oxygen deficiency $\delta$ was sequentially increased. Figure 35 shows a monotonically increasing Hall coefficient $R_H$ with $\delta$, where $\delta$ is estimated from the $c$-lattice parameter. Details of the normal state Hall coefficient as well as the procedure used to estimate $\delta$ were presented in previous chapters. Equally important were the observations of reproducible, systematic "noise" [see Figure 35] that formed
Example derivation of the Hall coefficient $R_H$ by application of Equation (1) to the two opposing Hall "signals" $R_{xy}$. This data set was obtained on a fully oxygenated, highly crystalline, coevaporated thin film of YBa$_2$Cu$_3$O$_7$. Notice the complete disappearance of the "peculiar" hump from the resulting Hall coefficient. The Hall "offset" (average of the opposing Hall "signals") was never observed to behave as a simple scaled down resistivity versus temperature curve. This suggests that the current paths do not travel exactly parallel to the patterned bridge. Moreover, these implied current paths probably vary with temperature.
Superconducting Hall effect transitions measured with $B = 8T$ for a single laser ablated film of YBa$_2$Cu$_3$O$_{7-\delta}$ at various estimated oxygen contents 7-δ. The reproducible, systematic "noise" observed below 7-δ ≈ 6.6 was later found to occur in all thin films. These are currently believed to occur as a result of oxygen clustering. Reproducibility is well established by the similarities that occurred before and after oxygen vacancy ordering of the "Ortho-II" phase in YBa$_2$Cu$_3$O$_{6.45}$. Below 30K, the "quenched" curve has been vertically displaced to avoid excessive overlap of data with the "ordered" curve. Note the small sign reversal of $R_H$ that occurred at full oxygenation. Error bars are estimated to be on the order of the size of the symbols.
in all of the thin films studied as the oxygen deficiency exceeded roughly $\delta \geq 0.4$, whereas these were never observed in the resistive transitions. This systematic "noise" is currently believed to result from a clustering of the chain-site oxygen atoms\textsuperscript{16} which, in turn, causes unusually strong "gyrations" to occur in the current paths as the temperature is swept.

It is believed that oxygen vacancy ordering can occur at room temperature in the "Ortho-II" phase, i.e., YBa$_2$Cu$_3$O$_{6.5}$\textsuperscript{100} This effect was observed in the laser ablated film depicted in Figure 35 near a fixed, estimated oxygen content of $7-\delta \approx 6.45$. The overall similarities between the systematic Hall "noise" taken before and after four days of room temperature annealing support the notion that these features are generated by the samples and not by the measurement process. In preparation for this experiment, this sample was quenched from 200°C, rapidly mounted, then cooled to below 250K in less than 30 minutes. The resulting data are plotted in the curve labeled "quenched" in Figure 35. The systematic "noise" was originally believed to somehow result from the subtraction process of the two Hall "signals" taken in opposing fields described in Chapter II. However, upon aging the sample at 297K for four days, the sequence was repeated to determine if any changes had taken place. Interestingly, the "ordered" curve in Figure 35 shows that the same characteristic "noise" reappeared but at a slightly higher temperature, probably due to the 10K increase in $T_c$. This leads to the conclusion that these features are most probably due to inhomogeneities in the materials and not to the subtraction procedure, e.g., Equation (1), used to calculate the Hall coefficient $R_H$. Most importantly, it is
suspected that the sign reversal of $R_H$ near 32K in the "ordered" curve results from current percolation due to an inhomogeneous distribution of resistivities. Finally, careful inspection of Figure 35 reveals that a sign reversal in the Hall coefficient occurred not only at $7-\delta = 6.45$, but at full oxygenation ($\delta = 0$), which suggests that both reversals have the same origin.

Final anneals at 550°C under 1 atm O$_2$ are usually conducted to determine whether or not any changes have occurred in the transport properties other than those due to variations in the oxygen content after a long series of sequential anneals. This procedure was performed on the laser ablated film for which a sign reversal occurred in $R_H$ at full oxygenation ($\delta = 0$). Afterwards, all of the starting properties, i.e., resistivity $\rho$, critical current density $J_c$, and transition temperature $T_c$, were completely restored to their initial full oxygenation values with the exception of the sign reversal of $R_H$ near $T_c$. Figure 36 shows that the superconducting Hall effect transition changed dramatically suggesting that these Hall transitions are highly sensitive to inhomogeneities in the oxygen content. Moreover, such dramatic effects prompted the series of computer simulations which are discussed in the next section.

**B. Current Percolation Model**

Contrary to the resistivity and critical current measurements which utilize large portions of the sample, the Hall effect demands smaller probes in order to minimize the "flaring" of the charge carriers into the Hall electrode region. Ideally, the Hall probes should be vanishingly small. These necessary small electrode dimensions (20 $\mu$m) lead
Changes in the superconducting Hall effect transition due to the series of sequential anneals for the laser ablated film shown in Figure 35, both of which were obtained at full oxygenation and with $B = 8T$. The curve labelled "final anneal" reveals the changes that resulted from these oxygen anneals, although $T_c$, $J_c$, and normal state resistivity returned to their original values. Notice the complete disappearance of the sign reversal of $R_H$ near $T_c$. 
to limited statistics which are probably responsible for at least some of the observations of the sign reversals of $R_H$. Therefore, a series of computer simulations of the superconducting Hall effect transitions was conducted utilizing Monte Carlo techniques to determine the percolative path of the current for various inhomogeneous mediums, while performing integrations to determine $R_H$. A total of 60 different spatial distributions with various Gaussian $T_c$ widths ($\Delta T_c \leq 6K$) were tested. Interestingly, one-sixth of the total distributions were found to lead to an apparent sign reversal of $R_H$. The Hall coefficients resulting from the simulations were defined by \cite{101}

$$dR_H = \frac{\rho(T,H)}{T^2} \cos \theta \, dl$$  \hspace{1cm} (86)

In this equation, the resistivity term $\rho(T,H)$ represents a typical set of resistive transitions [see Figure 43 in Appendix E]. In the actual computer simulations, the transitions were shifted up or down in temperature to represent the "local" $T_c$ of the distribution being tested. The $T^2$ term was artificially inserted to give the observed $R_H \propto 1/T$ dependence observed in the normal state. Finally, the $\cos \theta$ term represents the direction of the local current increment with respect to the overall applied potential. However, this does not exactly fit the experimentally observed scaling, i.e., $|\rho_{xy}| \propto \rho_{xx}^{1.7}$, between the superconducting Hall effect transitions and resistive transitions.\cite{102} The interest here is to determine the overall impact of current percolation on the superconducting Hall effect transitions, especially $R_H$ as a function of applied field. Monte Carlo methods, described in Appendix E, were utilized to determine the percolation paths of least resistance while integrating Equation (86). If
given a sufficiently large integration region, these effects become rather small. However, this is experimentally unfeasible since the electric currents would flare into the Hall probes, causing excessive offset signals and obscuring the real Hall signals.

The overall effect of current percolation on the Hall resistivities $\rho_{xy}$ is evident in Figure 37(a). This family of curves summarizes the results obtained for the 60 different $T_c$ distributions. Each random $T_c$ distribution coupled to a limited integration region always led to an overall progressive reduction of $\rho_{xy}$. These relative reductions rely mainly on the spatial layout of the $T_c$ contours in addition to the Gaussian $T_c$ widths. In one-sixth of all the distributions tested, these parallel-like reductions were large enough to cause a sign reversal of $\rho_{xy}$, with one such distribution leading to the calculated Hall coefficient $R_H$ as a function of temperature shown in Figure 37(b). Moreover, sign reversals occurred in some instances when the Gaussian $T_c$ width was as little as 2K. Notice that these sign reversals usually occur at the lowest applied fields, disappearing as the fields are increased. These curves are remarkably similar to those published elsewhere by various authors.\textsuperscript{24,25} Another important feature is the relative insensitivity of $\rho_{xy}$ to inhomogeneities while in the normal state. These features are simply explained by the argument that a $T_c$ distribution in small applied fields leads to a larger distribution of resistivities than that produced by larger fields. As the fields are increased, the resistive transitions are broadened, causing an overlap in the transitions of the various regions which leads to a reduction in the total level of the current "gyration." The sign reversals result whenever the current momentarily reverses direction in order to seek out a path of lower resistance. If these reversals
Figure 37

Hall effect transitions predicted by the Monte Carlo simulations. (a) Hall resistivities as a function of applied field resulting from differing degrees of inhomogeneity. Increasing levels of current "gyration" lead to the parallel-like downward shifts in these curves. In about one-sixth of the total $T_c$ distributions tested, these downward shifts were large enough to cause a sign reversal in $R_H$ near $T_c$. Note that percolation has little effect on the normal state Hall coefficient. (b) The Hall coefficient plotted as a function of temperature at three different applied fields determined for a preselected $T_c$ distribution that gives a sign reversal of $R_H$ near $T_c$.
occur in resistive regions \((T > T_c)\) while in proximity of the Hall probe, and if most of the other increments occur below \(T_c\) in this probe region, a sign reversal is likely. Thus, these reversals merely result from the limited statistics of the measurement due to the small probes. Finally, limited statistics are probably the cause for the sign reversal observed at full oxygenation in the laser ablated film depicted in Figure 36.

Nonuniform suppressions in the flux creep pinning energy\(^{103}\) due to nonuniform current densities were neglected in these Monte Carlo simulations. These effects are rather important near \(T_c\) since, significant current densities are required to measure the weak Hall signals. Moreover, these effects tend to maintain some spatial separation of the current paths occurring within the superconducting regions near \(T_c\), whereas these effects do not apply to the current paths occurring in the normal regions. As a result, current paths will not converge near any superconducting "necks." Such a case is illustrated in Figure 38 where these appear to be plausible current paths when the temperature is near 89K. Unfortunately, these current density dependencies on the flux creep dissipations are difficult to incorporate into the actual simulations. On the other hand, neglecting these dependencies do not alter the family of curves depicted in Figure 37(a), but rather, such neglects simply lead to underestimates in the total level of current "gyration" for a particular \(T_c\) distribution. Therefore, these simulations probably give too low of a reduction in \(\rho_{xy}\) for any given \(T_c\) distribution; as a result, the actual fraction of sign reversals of \(R_H\) is underestimated. Finally, it would be useful to study the "statistics" of Hall coefficient sign reversals in previous studies by others. If this picture is valid, it suggests that this effect is seen only part of the time.
VII. GRANULAR ORIENTED THIN FILMS

Oriented, deposited conductors hold potential for the fabrication of high-$T_c$ superconducting tapes, thereby prompting the desire to understand the physical properties of such systems. This chapter investigates the mechanism limiting the transport critical current density $J_c$ for two types of granular YBa$_2$Cu$_3$O$_{7-\delta}$ thin films: (1) c-oriented, but granular films grown on polycrystalline yttria-stabilized zirconia (YSZ) by pulsed laser ablation$^{104,105}$ and (2) triaxial epitaxial films [composed of small grains having either the (110) or (103) orientation] grown on (110) SrTiO$_3$ by coevaporation and post-annealing$^{106}$. Dimos et al. found relatively large $J_c$ values ($\approx 4 \times 10^6$ MA/cm$^2$ at 4.2K) at low angle grain boundaries (less than $10^6$) of YBa$_2$Cu$_3$O$_{7-\delta}$ suggesting the possible existence of percolation paths of high $J_c$ material in granular films. This implies a "scaled down", but otherwise similar $J_c(T,H)$ behavior as those seen in totally epitaxial films. On the contrary, the granular films presented in this chapter were found to behave as weak-link systems in the presence of giant Josephson vortices (described in some detail elsewhere$^{108}$). Typical values for zero resistance transition temperatures $T_c$ were near 88K and 67K, respectively, and $J_c(T=0)$ values were near 130 kA/cm$^2$ and 245 kA/cm$^2$, respectively.

In this study, I-V curves were acquired for a set of temperatures and applied magnetic fields, and all curves displayed behavior indicative of flux-creep-limited superconductors ($E \propto J$ in fields $H \ll H_{c2}$). The temperature dependence of $J_c(H=0)$ for either type of thin film was found to fit neither the SIS (superconductor-insulator-superconductor) model$^{109}$ nor any one of the SNS (superconductor-normal-superconductor)
superconductor) family of curves, parametrized by the ratio of barrier thickness to normal state coherence length, $L/\xi_N(T_c)$.\textsuperscript{86} However, critical current densities typically were two orders of magnitude below those of totally epitaxial films, and showed a strong dependence on the applied magnetic field history [Figure 39], indicative of a weak link system. For $c$-oriented films grown under the same conditions on both polycrystalline and single crystal YSZ (100) substrates, subtraction of the resulting polycrystal and single crystal resistivity curves $\rho(T)$, yield grain boundary resistivity curves which increase with temperature in a way consistent with dirty metals [see Figure 40]. In addition, using the measured grain size\textsuperscript{105} (0.2 - 1.0 $\mu$m), $L_cR_N$ products were determined to fall between 0.3 mV and 2.1 mV, which are well below those expected for SIS barriers, i.e., approximately 20 mV at $T = 0$.\textsuperscript{110} Rather, it is shown in the following that these granular thin films behave as SNS systems for which the critical current densities are further limited by thermal activation of self-field created Josephson vortices at the grain boundaries.\textsuperscript{108}

From the Anderson-Kim thermally activated flux creep model,\textsuperscript{111,112} in the limit of weak pinning barriers (e.g., at large applied magnetic fields), one expects a thermally activated creep resistivity $\rho = (dE/dJ)$ at $J=0$ given by,\textsuperscript{113}

$$\rho = \rho_0 \exp \left( \frac{U_0}{kT} \right),$$

(87)

where $U_0$ is the activation energy and $\rho_0$ is at most a slowly varying function of $T$ involving the flux lattice response. Thus, the systematic determinations of $\rho$ as a function of field and temperature yield activation energies\textsuperscript{114} with the temperature

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Polycrystalline Thin Film

4.2K  H||ab

\[ (j = H) / J_c \]

\[ J / J_c \]

H (kOe)

1

0.1

0.1

1

10

100

Critical current density hysteresis as a function of applied magnetic field history for a c-oriented granular YBa_2Cu_3O_7 thin film. These data were obtained at 4.2K with the field oriented parallel to the \( ab \)-plane. Similar effects were observed at other field orientations and at higher temperatures. These results are indicative of a Josephson mixed state.\(^{115}\)
"Grain boundary" resistivities obtained by subtracting several polycrystalline $c$-oriented YBa$_2$Cu$_3$O$_7$ resistivity curves $\rho(T)$ from a single crystal resistivity curve grown under similar conditions. The temperature dependencies for these samples are consistent with dirty metals [i.e., maximum $\rho(T)$ at $T \gg 0$K and $\rho(T=0) \gg 0$].
dependencies shown in Figure 41. The field dependencies of the activation energies could be described by

\[ U_o(T, B) \propto \frac{1}{(B + B_o)^{0.15}}, \text{ for the c-oriented films} \]  \( (88) \)

\[ U_o(T, B) \propto \frac{1}{(B + B_o)}, \text{ for the triaxial films.} \]  \( (89) \)

The constant \( B_o \), taken to be approximately 10G, is included to prevent \( U_o(T, B) \) from diverging under self-fields near \( T_c \). The prefactor, \( \rho_o \), is explicitly given by

\[ \rho_o = \left( \frac{E_o}{J_{co}} \right) \left( \frac{U_o}{kT} \right), \]  \( (90) \)

where in the present case \( J_{co} \) is taken as an SNS critical current density in the absence of flux creep. The parameter \( E_o \), which is proportional to the elementary "attempt" frequency for flux hops, can be estimated by scaling the experimental I-V curves to the Anderson-Kim expression,\(^{111,112}\)

\[ E = E_o \exp \left( -\frac{U_o}{kT} \right) \sinh \left[ \left( \frac{J}{J_{co}} \right) \left( \frac{U_o}{kT} \right) \right]. \]  \( (91) \)

For the granular films studied, the \( E_o \) values were found to have temperature dependencies somewhat similar to the respective activation energies. Interestingly, these \( E_o \) dependencies are in qualitative agreement with the prediction of Feigel'man et al. for collective thermally activated processes in the vortex state\(^{116}\). 

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Temperature dependence of the activation energy at an applied field of 1 Tesla for triaxial and c-oriented granular thin films of YBa$_2$Cu$_3$O$_y$. The curves are empirical fits to the experimental data (symbols) for use in the flux creep models.
\[ E_c = \rho_{\text{flow}} \frac{U_o}{T} \]  \hspace{1cm} (92)

Self consistency of this model is shown for both types of granular films by substituting the \( U_o \) and \( E_c \) parameters, determined in the dissipative state, into the relationship for a creep-limited \( J_c \):\(^{50}\)

\[ J_c = J_{\text{co}} \left( \frac{kT}{U_o(T,B)} \right) \sinh^{-1} \left( \frac{E_c}{E_o} \exp \left( \frac{U_o(T,B)}{kT} \right) \right), \]  \hspace{1cm} (93)

where \( E_c \) is the electric field criterion of 1 \( \mu \)V/cm. Here, the self fields, \( B \), are assumed to be proportional to the current density\(^{117}\) and are on the order of 100G at 4.2K, estimated from the \( J_c(H) \) data. In Figure 42(a) and Figure 42(b), best fits to the experimental data, for both types of film, are found by choosing the \( J_{\text{co}} \) function as the Likharev SNS curve\(^{86}\) for which \( L = 3.5 \xi(N,T_c) \). Even though the activation energies differ markedly, this model provides a good description of the experimental \( J_c \) data in both cases. The slight discrepancies which occur above \( t \approx 0.7T_c \) could be ascribed to a number of effects, including high-temperature fluctuations, or simply errors in extrapolating high-field \( U_o \) values to the limit of self fields.

In conclusion, a self-consistent model for \( J_c(T,H=0) \) was shown for two types of granular-oriented \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) thin films. In both cases, the self field was found to penetrate along the grain boundaries producing a Josephson mixed state.\(^{118}\) The thermal activation energies of the resulting Josephson vortices, determined in the limit of large magnetic fields, were found in the triaxial films to behave as those seen in totally epitaxial films but scaled down by one order of magnitude. Unlike the triaxial
Reduced critical current density $J_c(T)/J_c(0)$ versus reduced temperature for the granular YBa$_2$Cu$_3$O$_7$ films. Symbols show experimental results for the (a) $c$–axis oriented and (b) triaxial thin films. In comparison, the solid curves show the conventional SIS and SNS weak link models and the SNS model with flux creep dissipation.
films which contain only special grain boundaries, the $c$-oriented granular films having random $ab$-plane grain boundaries were found to have even lower activation energies which exhibit maxima at temperatures near $0.8T_c$. Finally, thermally activated flux creep of the Josephson vortices applied to an SNS weak-link system\textsuperscript{86} was shown to reproduce the experimentally measured critical current densities.
VIII. SUMMARY

The effects of oxygen deficiency on the resistivity, Hall coefficient, and critical current density were measured on a series of eleven epitaxial $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ thin films. Solder free gold contacts and pressure pads facilitated the changing of the oxygen content by sequential anneals under carefully controlled conditions. All of the inverse Hall coefficients have linear temperature dependencies, as predicted by the Luttinger liquid theory,\textsuperscript{75} and the implied carrier densities steadily diminish with increasing oxygen deficiency $\delta$. Moreover, the relative insensitivity of the Hall angle to oxygen deficiency suggests that only one of the four predicted electronic bands crossing the Fermi level\textsuperscript{7} dominates the normal state properties with fields $\mathbf{H}\parallel\mathbf{c}$. Critical currents extrapolate to zero as the oxygen content nears the edge of the 90K plateau, suggestive of phase separation in which only the fully oxygenated phase has the high critical current density. Over much of the 90K plateau, no changes are seen in the pinning energies, further supporting this phase separation picture. However, electronic origins for the $T_c(\delta)$ plateaus were considered since pinning energies also depend on the coherence lengths $\xi$. Increases in $\xi$ could account for the pinning energy plateau while allowing decreases of $J_{\infty}$ with $\delta$ to lead to the decreases of the critical current densities $J_c(\delta)$. Any increase in $\xi$ should lead to a corresponding decrease in the $H_{c2}$ slope near $T_c$. Therefore, the fluctuation theory of Ullah and Dorsey\textsuperscript{21} in the limit of large magnetic fields was applied to the in-field resistive transitions obtained from two of the epitaxial thin films of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ at various oxygen deficiencies $\delta$. In both samples, an $H_{c2}$ plateau corresponding to an $H_{c2}$ slope of $-1.7$ T/K was observed for
oxygen deficiencies occurring on the 90K plateau, e.g., in the range $6.8 \leq \delta \leq 7.0$. In contrast, the in-field resistive transitions taken off the 90K plateau, e.g., $\delta \geq 0.2$, were not adequately described by the fluctuation theory and may suggest the presence of such phase separation, whereas, evidence for granular-like behavior was observed in the Hall transitions and the field dependence of $J_c/J_c(H=0)$ when $\delta \geq 0.3$. Since an $H_{c2}$ plateau was also observed in a recent Hao et al. analysis of the magnetization measurements$^{83}$ of bulk, aligned YBa$_2$Cu$_3$O$_{7-\delta}$, the plausible existence of an $H_{c2}$ plateau as a function of oxygen deficiency $\delta$ supports the extrinsic origin of phase separation occurring on the 90K and 60K $T_c$ vs. $\delta$ plateaus.

The non-universal observation of a sign reversal of $R_H$ near $T_c$ also suggests that the superconducting transitions are highly sensitive to the effects of extrinsic inhomogeneities. Therefore, Monte Carlo simulations of the superconducting Hall effect transitions were conducted assuming various random $T_c$ distributions. The results clearly show that the occasional observation of a sign reversal of $R_H$ can be attributed to inhomogeneities such as the oxygen content in YBa$_2$Cu$_3$O$_{7-\delta}$. Experimental results consistent with this picture were presented. Similar effects could also be ascribed to variations in the sample thickness that, near the observed $T_c$, would tend to smear the local $T_c$'s due to uneven depressions of the pinning energies resulting from current density variations. These results do not rule out the possibility of intrinsic flux motion effects in the limit of weak pinning energy; however, the non-universal observations of the sign reversals of $R_H$ undoubtedly make such explanations very difficult. Therefore, it is most probable that most of the observed sign reversals in the high-$T_c$
materials are *extrinsic* in origin.

In the polycrystalline thin film studies, a self-consistent model for \( J_c(T,H=0) \) was shown for two different types of granular-oriented YBa\(_2\)Cu\(_3\)O\(_{7-\delta}\) thin films. In both cases, the self field was found to penetrate along the grain boundaries producing a Josephson mixed state.\(^{118}\) The thermal activation energies of the resulting Josephson vortices, determined in the limit of large magnetic fields, were found in the triaxial films to behave as those seen in totally epitaxial films but scaled down by one order of magnitude. Unlike the triaxial films that contain only special grain boundaries, the \( c \)-oriented granular films having random \( ab \)-plane grain boundaries were found to have even lower activation energies that exhibit maxima at temperatures near \( 0.8T_c \). Finally, thermally activated flux creep of the Josephson vortices applied to an SNS weak-link system\(^{86}\) was shown to reproduce the experimentally measured critical current densities.

In sum, the most important findings from this work are as follows. First, only a small part of the band structure, i.e., perhaps a single band, appears to dominate the normal state properties. Second, *extrinsic* inhomogeneities of the oxygen content can account for the 90K and 60K plateaus in \( T_c \) vs. \( \delta \) due to the short coherence length \( \xi \). Third, the superconducting transitions are highly sensitive to the effects of inhomogeneities. Fourth, the grain boundaries behave as normal metal barriers instead of ideal Josephson junctions. Finally, it is recommended to use caution when deciding whether a particular property of these new high-\( T_c \) materials is *intrinsic* or *extrinsic*. 

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REFERENCES
A. Text References

9. J. Yu (private communication).


31. Sign reversals of $R_H$ near $T_c$ are often reported to occur at low fields ($B < 5\text{T}$), disappearing at higher fields. This is not the case with the coevaporated films.


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45. R. Feenstra has shown this to be a universal result in thin films. (unpublished).


48. Note that the triple point of nitrogen is 63K. Thus, the 52K quoted here is obtained by subliming the nitrogen.


51. D. K. Christen (private communication).

52. H. R. Ketchner (private communication).


56. In the high-field limit, $E_x$ saturates and no longer depends on the external field $B$. Since the field strengths required are currently inaccessible to most instruments (range of ~ 100T), this regime is not considered in this dissertation.


58. G. D. Mahan calculated $R_\parallel(T)$ and $\rho(T)$ for the case of strong electron–electron scattering between two bands. (unpublished) In this case, every quantity is simply the average of the two bands. Unfortunately, the Hall coefficient remains independent of temperature in this scenario.


68. G. D. Mahan remarked that this equation is only valid for the case of elastic scattering of electrons from impurities; fortunately, the resulting transport coefficients predict accurate values for the conductivity and the Hall coefficient in most metals. Nevertheless, it would be desirable to develop a set of transport coefficients starting with the Boltzmann equation valid for electron-phonon scattering.


71. A similar procedure, for the case N=2, leads to the result \( \sigma = \text{scalar} \). For details, see Ref. 61.


98. Accepted values for $H_{c2}(0)$ ($H \parallel c$) generally occur in the range 1000–1250 kOe as obtained from References 18 and 19.


101. Electric fields parallel to the current paths are not considered here since, these are even functions of the magnetic field. Thus, these signals cancel from the defined Hall coefficients upon application of Equation (1).


B. Appendix References


C. Suggested Hall Effect Readings


APPENDICES
Appendix A. Hall (Resistivity) Acquisition Program

10 DEFINT IN
20 '*** HALL.BAS ***
40 '--- KELTHLEY 570 SYSTEM ---
50 '--- V-VOLTAGE VS X-VOLTAGES -- PERSONAL88 DATA ACQUISITION ---
100 'DATA SAMPLED AFTER SPECIFIED X & Y-ABS-VALUE-INTERVALS HAVE PASSED
110 'OUTPUTS X1, X2, X4 AND Y DATA TO AN ASCII FILE
120 'SPECIFIED BY THE USER. PLOTS AUXILIARY DATA FILE FOR COMPARISON
130 'COMMAND TO SEND TO Y-DVM FOR K-18 TURNS OFF DIGITAL FILTERING
135 'SWITCHES K-224 POWER SUPPLY BETWEEN + & - OUTPUTS TO CANCEL THERMAL EMF'S
136 'FROM THE NANOVOLTMETER SIGNAL. TEMP. SIGNAL & MAG. SIGNALS ARE NOT
137 'CORRECTED FOR THERMALS SINCE TRANSPORT CURRENTS ARE RELATIVELY LARGE!
140 'X1-channel is converted to a temperature (optional).
142 'X2-channel verifies the K-224 output current and corrects the data ...
144 'X3-channel measures a 3rd signal such as rho(T) when K-181 is in use.
145 'X4-channel measures the magneto current if not in persistent mode
146 'Y-voltmeter measures the Hall signal which can be plotted
148 'Magnetic field determined assuming use of a 1/100 ohm std. resistor.
150 'DATA OUTPUT: (1) If desired, will sort data according to X1-signal (temp)
151 'when saving data to the disk in standard format.
152 ' (2) If X1-signal was converted to a temperature & after
153 'sorting data, will prompt user to continue with a
154 'temperature interpolation routine controlled by user
155 'parameters Tmin, Tmax, & T-interval.
156 ' This new data is then saved to the disk.
160 'Maintains Temperature Controller Set Point to values based on user
162 'input and current sample temperature (optional).
190 '*** MAIN PROGRAM ***
210 '220 GOSUB 400 '--- SET DEFAULT PARAMETER VALUES ---
225 GOSUB 4150 '--- READ IN FILE OF SETUP AND GRAPHICS PARAMETERS ---
230 GOSUB 700 '--- SIGN-ON & HARDWARE SETTINGS MENU ---
240 GOSUB 1000 '--- SETUP PARAMETERS MENU ---
245 GOSUB 4500 '--- STORE SETUP AND GRAPHICS PARAMS TO FILE ---
250 GOSUB 1600 '--- DATA ACQUISITION INITIALIZATION ---
260 GOSUB 1750 '--- TAKE ONE DATUM SAMPLE ---
270 GOSUB 3550 '--- CHECK FOR KEYBOARD INTERRUPT ---
280 GOSUB 1850 '--- TEST DATA FOR OUTPUT ---
290 GOSUB 1550 '--- CHECK FOR KEYBOARD INTERRUPT ---
300 GOSUB 3750 '--- CALC. TEMP. FROM THERM. CALIBRATION ---
305 IF TSET$='ACTS THEN GOSUB 900 '--- TEMPERATURE CONTROLLER SET POINTS ---
310 GOSUB 200 '--- PRINT DATA TO DISK ---
320 GOSUB 2700 '--- PLLOT OR PRINT DATA TO SCREEN ---
330 GOSUB 3550 '--- CHECK FOR KEYBOARD INTERRUPT ---
340 GOTO 260 '--- LOOP BACK FOR MORE DATA ---
350 '360 '*** END MAIN PROGRAM ***
370 '380 '390 '400 '*** DEFINE DEFAULT PARAMETERS ***
410 CT8: KEY OFF: KEY I,'"LIST 200-400"+CHR$(13)
420 DEFINE LN
425 JD=700 'JD=1400 for ~ 25 sec delay to allow DVM triggering
430 DIM X(500),X(250),X(450),Y(500) 'DIM DATA FOR GRAPHICS REFRESH
440 DIM V(500),T(500) 'ARRAY FOR THERM. CALIBRATION TABLE(e.g. DIODE Y,T
445 DIM XQ(500),YQ(500) 'ARRAY OF COMPARISON DATA FOR GRAPHICS
450 ON ERROR GOTO 5400 '---ERROR TRAPPING
460 RESTORE 470
470 DATA 10.1,0.1,1.1.,1.,10000*0.1'
480 READ CUR,SCALEX,SCALEY,D,DELY,0%,G1%,NFRITS,CURRNTS,DELMAG'Defaults
490 CURR$="+"+CURRNTS
492 CNREG$="+"+CURRNTS
495 SCALEX2=SCALEX: SCALEY=1: SCALEMAG=102.91 'Hall Cryostat & 1/100 Ohm Std.
490 DATA "<INACTIVE","<ACTIVE>"
500 READ INACTS,ACTS; GSET5=INACTS GCSET5=INACTS TSET5=INACTS
504 ' --- GPIB BUS ADDRESSES & METER PARMS
505 DATA * "26", "14","KEITHLEY 111/197","KEITHLEY 181/197","NMSK = 5"," KEITHLEY 224"
506 READ XADDRS,YADDRS,MXS,MYS,NUM Y, N, XMAX, YMAX
507 TADDR$="12" 'Temp. Controller GPIB Address
510 ' 520 'GRAPHICS DEFAULT PARAMETERS
521 PLOTS="T" VUITS="N"
527 RATIO=1000 'Typical E-ph/E-hall ratio
530 RESTORE 550
540 READ XMIN, XMAX, YMIN, YMAX
550 DATA 0,300,0,5,0,5,0
560 READ X$Y$1, Y$2, T$4
570 RESTORE 590
580 READ X$Y$1, Y$2, T$4
590 DATA "X1-AXIS(UNITS)","Y-AXIS","(UNITS)","TITLE OF HALL GRAPH"
600 RESTORE 620
610 READ DXPIX,DYPIX, XPIX0,YPIX0 'AXIS CONSTANTS IN PIXELS
620 DATA 510,300,30,15
630 RETURN 'TO MAIN PROGRAM
640 ' 650 ' 700 *** SIGN-ON HARDWARE SETTINGS MESSAGE ***
710 CLS; PRINT CHR$(7)
720 PRINT;PRINT " *** HARDWARE SETTINGS ***
730 PRINT "1: X-INPUT: GPIB Address: ";XADDR$; " Meter ID: ";MX$;
740 PRINT "2: Y-INPUT: GPIB Address: ";YADDR$; " Meter ID: ";MY$;
744 PRINT
745 PRINT " Set ;$; Power Supply GPIB Address to ;$TADDR$
746 PRINT " and the Voltage Compliance to a Safe Value."
747 PRINT
748 PRINT " K-190 SETUP: Temp. signal < == > X-Channel # 1"
749 PRINT " Curr. signal < == > X-Channel # 2"
750 PRINT " Alt. signal < == > X-Channel # 3"
751 PRINT " Max. current < == > X-Channel # 4"
752 PRINT " K-181 NANOVOLTMMETER: Hall or Rho Signal";PRINT
754 PRINT " Reset LakeShore Temperature Controller & set GPIB address to ;$TADDR$
755 PRINT
760 INPUT "ENTER SELECTION # (<C/R> TO CONTINUE): ";ICODE
770 ON ICODE GOTO 790,810
780 RETURN 'TO MAIN PROGRAM
790 INPUT "ENTER NEW GPIB ADDRESS FOR X-INPUT: ";XADDR$;
791 COSUB 850 ' --- METER ID CHOICES FOR READING STRING MASKING
792 INPUT "ENTER X-INPUT Meter ID CODE (DEFAULT = PREVIOUS): ";,NMT
794 IF NMT < > 0 THEN NM=NMT ELSE 100
795 COSUB 900 MXS=M$; NXM=NMSK ' -- ASSIGN METER ID NAME & MASKING DATA
800 XADDR$=STR$(XADDR$); GOTO 720
810 INPUT "ENTER NEW GPIB ADDRESS FOR Y-INPUT: ";YADDR$
811 COSUB 850 ' --- METER ID CHOICES
812 INPUT "ENTER Y-INPUT Meter ID CODE (DEFAULT = PREVIOUS): ";,NMT
814 IF NMT < > 0 THEN NM=NMT ELSE 120
815 COSUB 900 MY$=M$; NYM=NMSK ' -- ASSIGN METER ID NAME & MASKING DATA
820 YADDR$=STR$(YADDR$); GOTO 720
830 ' 840 ' 880 ' 900 ' *** ASSIGN STRING MASKING PARAMS FOR METERS ***
880 PRINT " *** Meter ID Codes ***
885 PRINT* 1: " ;'KEITHLEY 111,197
886 PRINT* 2: " FLUKE 840A"
886 RETURN
890 ' 900 ' *** ASSIGN METER ID NAME ***
910 ON NM GOTO 930,940
920 PRINT CHR$(?); PRINT " < <WRONG METER ID> > "; RETURN 230
930 MS="KEITHLEY 181/197"; NMSK = 5: RETURN

147
940 M5="FLUKE 8840A": NMSK = 1: RETURN
950 ' 960 *
1000 SCREEN 0:CLS
1010 GOSUB 5500 " INCREMENT EXTENSION ON DATA FILENAME
1020 PRINT: PRINT: PRINT: PRINT " *** SET-UP PARAMETERS *** "
1030 PRINT " 1: FILENAME OF SETUP AND GRAPHICS PARAMETERS TO USE: ":PUFLS
1040 PRINT " 2: FILENAME OF SETUP AND GRAPHICS PARAMETERS TO SAVE TO: ":PSFLS
1050 PRINT " 3: X1-VOLTAGE SCALE FACTOR (Temp Signal/Vmeas): ":SCALEX
1060 PRINT " 4: X1-SIGNAL STEP SIZE: ":DEL
1062 PRINT " 5: X2-SIGNAL SCALE FACTOR (Ohm/Ohm): ":SCALEF
1065 PRINT " 6: X3-VOLTAGE SCALE FACTOR (All Signal/Vmeas): ":SCALEX2
1070 PRINT " 7: Y-VOLTAGE SCALE FACTOR (Nano Signal/Vmeas): ":SCALEY
1080 PRINT " 8: Y-SIGNAL STEP SIZE: ":DELY
1085 PRINT " 9: MAG. FIELD STEP SIZE (Gauss): ":DELMAG
1090 PRINT "10: DATA FILENAME: ":DNMS
1095 IF INMS = " THEN GOTO 1110
1100 PRINT " TITLE: ":TITLS
1110 PRINT " THRM. CAL. TABLE FILENAME (for X1-signal conversion): ":THNMS
1112 IF THNMS = " THEN GOTO 1170
1115 PRINT " TITLE: ":THTILS
1120 PRINT "12: NO. OF SAMPLES IN DIGITAL FILTERING: ":NFLT
1130 PRINT "13: SCREEN GRAPHICS PARAMETERS SETUP: ":GSETS
1132 PRINT "14: TRANSPORT CURRENT: ":CTNTS
1135 PRINT "15: ENTER PROGRAM: ":ENT
1137 PRINT "16: TEMPERATURE CONTROLLER: ":TCTRLS
1138 IF TCTRLS = " THEN PRINT " Controlled Range = " TC1", TC2" 
1139 IF VAP-SAMP = " THEN TCDEL , K@ R7"
1140 PRINT "17: INTERPOLATE FILE GIVEN IN OPTION 10 ACCORDING TO TEMPERATURE:"
1145 PRINT
1150 INPUT " > ENTER SELECTION #: (< CR > TO EXECUTE): ":THEOD
1160 ON THEOD GOTO 1460,1470,1290,1310,1467,1322,1180,1200,1212,1220,1300,1330,1350,1460,1325,1478,1482
1170 RETURN " TO MAIN PROGRAM
1180 INPUT " ENTER Y-VOLTAGE SCALE FACTOR (Nano Signal/Vmeas): ":SCALEY
1190 GOTO 1200
1200 INPUT " ENTER Y-SIGNAL STEP SIZE: ":DELY
1210 GOTO 1260
1212 INPUT " ENTER MAGNETIC FIELD STEP SIZE (Ko): ":DELMAG
1214 GOTO 1260
1220 INPUT " ENTER DATA FILENAME (EXT. .Dn WILL BE ADDED IF NOT ENTERED): ":DNMS
1222 IF INMS = " THEN 1280
1240 PRINT " ENTER 80 CHARACTERS DATA SET TITLE (DEFAULT = PREVIOUS): ":SEND
1250 IF INMS = " THEN 1270
1260 TITLES = DNMS
1270 FOR I = 1 TO LEN(DNMS): IF MID(DNMS,I,1) <> " THEN NEXT J ELSE 1280
1272 DNMS = DNMS + " DTG"
1280 GOTO 1260
1290 INPUT " ENTER X1-VOLTAGE SCALE FACTOR (Temp Signal/Vmeas): ":SCALEX
1300 GOTO 1260
1310 INPUT " ENTER X1-SIGNAL STEP SIZE: ":DEL
1320 GOTO 1260
1322 INPUT " ENTER X3-VOLTAGE SCALE FACTOR (All Signal/Vmeas): ":SCALEX2
1324 GOTO 1260
1330 GOSUB 2230 " Define Graphics Parameters
1332 GOTO 1260
1335 GOSUB 4500: END " STORE PARAMS TO FILE AND PREPARE TO EXIT
1336 PRINT": "OUTPUT";PADDLE:";RFNEX: "END " turn off current
1340 GOTO 1260
1350 INPUT " ENTER THERMOM. CALIB. TABLE FILENAME (EXT. .CAL WILL BE ADDED): ":THNMS
1360 IF THNMS = " THEN 1370 ELSE THNMS = THNMS + ":CAL"
1365 GOSUB 3900 " READ IN THERM. CALIB. DATA ...
1370 GOTO 1260
1380 INPUT " ENTER NO. SAMPLES IN DIGITAL FILTERING: ":NFLT
1390 GOTO 1260
1400 INPUT " ENTER FILENAME FOR SETUP PARAMS. TO USE (EXT. .PAR WILL BE ADDED): ":PUFLS
1410 IF PUFLS = " THEN 1430 ELSE PUFLS = PUFLS + ":PAR"
1420 GOSUB 4150: GOTO 230 " READ IN SETUP AND GRAPHICS PARAMS
1430 INPUT " ENTER FILENAME FOR SETUP PARAMS. TO SAVE TO (.PAR WILL BE ADDED): ":PSFLS
1440 IF PSFLS="*" THEN 1450 ELSE PSFLS=PSFLS+"."+PAR'
1450 GOTO 1020
1460 INPUT " Enter CURRENT IN AMPS [a.an.b(sign)]: ".CURRNTS
1461 CURRNTS="*"+CURRNTS
1462 CNGS="*"+CURRNTS
1465 GOTO 1020
1467 INPUT " Enter CURRENT SIGNAL SCALE FACTOR (1/STD Ohms): ",SCALE
1470 GOTO 1020
1475 IF THMMS="*" THEN PRINT " Enter a temperature calibration file if you plan to use the controller!: ": GOTO 1020
1476 IF TS$7S="*" THEN TSETS=INACT$ : GOTO 1020
1477 PRINT " Temperature Controller Settings: ": TSETS=ACTS
1478 INPUT " Enter Tmin, Tmax & Vap-Sump Set Points. , Tl, T2, T2DEL
1479 IF TCI > T2 OR TCI < 0 THEN PRINT " Bad Entry! ": GOTO 1478
1480 GOTO 1020
1482 INPUT " Are you sure? <Y=Yes > *=R
1484 IF R$="Y" OR R$="Y" THEN GOTO 1485 ELSE GOTO 1020
1485 IF DNMS="*" THEN PRINT " Must specify a data set to interpolate!: ": GOTO 1020
1486 CLOSE1
1487 OPEN1, #1, DNMS
1488 INPUT1, #1, TITLES
1489 INPUT1, #1, "No. of data points"
1490 FOR J = 1 TO 1
1491 INPUT1, #1, X(J),Y(J),X(J),Y(J)
1492 NEXT J
1493 CLOSE1
1494 IF THMMS="*" THEN THMMS="*"
1495 GOSUB 6000
1496 IF THMMS="*" THEN THMMS="*"
1497 GOTO 1020
1498 ' 1500 " " OPEN DATA FILE " "
1510 IF DNMS="*" THEN 1550
1520 OPEN "O", #1, DNMS
1530 PRINT #1, TITLES
1540 PRINT #1, "Temp-Signal Ac-Signal Nano-Signal H(#o)"
1550 RETURN
1560 ' 1570 ' 1600 " " *** INITIALIZATION FOR DATA ACQU. ***
1604 CURRS="*"+CURRNTS
1605 CNEG$="*"+CURRNTS ' -- NEG CURRENT STRING
1606 GOSUB 4020 ' -- PRINT MESSAGE AT SCREEN BOTTOM
1610 GOSUB 4850 ' -- INITIALIZE DATA AARRAY INDEX
1620 GOSUB 4850 ' -- ESTABLISH COMMUNICATION W/PERSONAL188
1640 GOSUB 4950 ' -- SIGNAL MESSAGE
1650 GOSUB 5550 ' -- ASSIGN REMOTE MODE ADDRESSES
1660 FLOGS="L" ' -- INITIALIZE FOR DATA SCREEN PRINTOUT
1680 GOSUB 1300 ' -- OPEN DATA FILE
1690 VXFLG=0 ' -- FLAG FOR FIRST TIME THRU
1700 PRINT " ***Beginning Data Acquisition ***" 1710 RETURN ' TO MAIN PROGRAM
1720 ' 1730 ' 1750 " " *** TAKE DATA SAMPLE ***
1760 ' -- GPB INPUT
1770 GOSUB 5100 ' -- FIN TO AVG OF NEILT GPB READINGS
1780 VX=SUMX*SCALEX; YX=SUMY*SCALEY; VMAG=SUMX*SCALEMAG
1790 VERC=VERSEC ' -- Actual K-224 current output
1787 VY=VY/VAL(CURRS)/VERC ' -- Correction for K-224 current drift
1788 VX2=VX2/VAL(CURRS)/VERC ' -- Correction for K-224 current drift
1790 RETURN ' TO MAIN PROGRAM
1800 ' 1810 ' 1850 " " *** DATA TUST FOR OUTPUT ***
1850 IF VXFLG=0 THEN VXFLG=1; VX=VX; YY=VY; VMAG=VMAG: RETURN ' 1st Pass
1870 DELVX=VX-VXT; DELY=VY-YY; DELVM=VMAG-VMAG
1880 IF IDATFLG=0 THEN 1920
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1890 IF INKS < > "T" AND INKS < > "P" THEN PRINT "MANUAL STORE"
1900 PRINT CHR$(?); " BELL TO INDICATE MANUAL DATA STORAGE"
1910 DATAPO=0: GOTO 1970 *MANUAL DATA STORAGE
1920 IF DEL=0 THEN 1970
1930 IF DELMG=0 THEN 1970
1940 IF DELY=0 THEN 1970
1950 IF ABS(DELVY) >= DELY THEN 1970 *STORE DATA
1960 IF ABS(DELXV) >= DELX THEN 1970 *STORE DATA
1960 IF ABS(DELXV) >= DELX THEN 1970 ELSE RETURN 360 *TAKE MORE DATA
1970 VX=VX: VY=VY: VMAG=VMAG: RETURN TO MAIN PROGRAM
1980 .
1990 .
2000 ** PRINT VALUES ON DISK **
2010 I=I+1: X2(I)=X2: Y2(I)=Y2: X4(I)=X4: VMAG=VMAG*INCREMNT INDEX
2020 IF THNMS="" THEN X(I)=X: GOTO 2040
2030 X(I)=T
2040 IF DNMS="" THEN 2060
2050 PRINT #1,X(I),X2(I);Y(I),Y2(I)
2060 RETURN TO MAIN PROGRAM
2070 .
2080 .
2100 ** TEST TO REDUCE GLOBAL GAIN **
2110 IF VTST>=50 THEN GS=1: GOTO 2150
2120 IF VTST>=2 THEN GS=2: GOTO 2150
2130 IF VTST>=1 THEN GS=5: GOTO 2150
2140 GS=10
2150 RETURN
2160 IF VTST="" THEN GT%""=G%: GSUB 1790: RETURN 'CHANGE TO NEW X-GAIN
2170 GS%""=G%: GSUB 1790 'CHANGE TO NEW Y-GAIN
2180 RETURN
2190 .
2200 .
2250 ** SCREEN PARAMETERS **
2255 SCREEN D,CLS
2260 GSETS=ACTS.'SCREEN GRAPHICS ACTIVE.
2270 PRINT: PRINT: PRINT: *** SCREEN GRAPHICS PARAMETERS ***
2275 PRINT' 1: PLOT TYPE (T=K=181 vs Temp.. & H=K=181 vs Field): *.PLOTS
2280 PRINT' 2: X-axis Xmin, Xmax: *.XMIN,XMAX
2290 PRINT' 3: Y-axis Ymin, Ymax: *.YMIN,YMAX
2300 PRINT' 4: X-axis label: *.XS
2310 PRINT' 5: Y-axis label: *.YS, YS
2320 PRINT' 6: Graph Title: *.T
2325 PRINT' 7: COMPARISON DATA SET FILENAME: *.GCOMFLS
2326 IF GCOMFLS="" THEN GOTO 2327 ELSE PRINT "TITLE: *.GTLS
2327 PRINT' 8: VIEW COMPARISON DATA SET: *.GSETS
2328 PRINT' 9: Ratio of F-alt/F-site: *.RATIO
2329 PRINT' 10: Include alt data in plots? (Y=Yes; N=No): *.VUTS
2330 PRINT
2340 INPUT: > ENTER SELECTION # ( <COR > TO CONTINUE): *.ICODE
2350 ON ICODE GOTO 2362,2370,2390,2410,2430,2470,2483,2452,2366
2355 CLS
2360 GOTO 2490
2362 INPUT: > ENTER PLOT TYPE (T=K=181 vs Temp.. & H=K=181 vs Field): *.PLOTS
2363 IF PLOTS="" THEN GOTO 2270
2364 IF PLOTS="" THEN GOTO 2270
2365 PRINT "Error" : BEEP : GOTO 2362
2366 INPUT: > INCLUDE ALT DATA IN PLOTS? (Y=Yes; N=No): *.VUTS
2367 IF VUTS="" THEN GOTO 2270
2368 IF VUTS="" THEN GOTO 2270
2369 PRINT "Error" : BEEP : GOTO 2366
2370 INPUT: > ENTER X-axis Xmin, Xmax: *.XMIN,XMAX
2380 GOTO 2270
2390 INPUT: > ENTER Y-axis Ymin, Ymax: *.YMIN,YMAX
2400 GOTO 2270
2410 INPUT: > ENTER X-axis label: *.XS
2420 GOTO 2270
2430 INPUT: > ENTER Y-axis label: *.YS
2440 FOR J = 1 TO LEN(Y$); IF MID$(Y$, J, 1) < > "" THEN NEXT J
2450 Y$ = LEFT$(Y$, J - 1); J = LEN(Y$) - J + 1: Y$ = RIGHT$(Y$, J)
2460 GOTO 2270
2462 INPUT * ENTER Typical Echo/Echo Value: * RATIO
2464 GOTO 2270
2470 INPUT * ENTER Graph Title: *, X
2480 GOTO 2270
2481 IF FIXITS = "NO" THEN GOTO 2270 ELSE INPUT * ENTER COMPARISON FILE: *, GCOMPL$S
2482 GOSUB 5800: GOTO 2270 'READ IN DATA SET FROM FILE
2483 IF FIXITS = "NO" THEN GOTO 2270 ELSE INPUT * VIEW PLOT OF DATA SET (Y = YES)? * ANS$
2484 IF ANS$ = "Y" OR ANS$ = "Y" THEN OSCSETS = ACTS ELSE OSCSETS = INACTS: GOTO 2270
2485 GOSUB 2490 'DEFINE GRAPH AXIES RANGES
2486 GOSUB 5900 'PLOT DATA SET
2487 GOSUB 4111 'PRINT MESSAGE AT SCREEN BOTTOM
2488 IF INKEY$ = "" THEN GOTO 2418 ELSE SCREEN 0: GOTO 2270
2489
2490 XMIN = XMIN: YMIN = YMAX-YMIN
2500 XMAX = STR$(XMIN): XMAX = STR$(XMAX)
2510 YMINS = STR$(YMIN): YMINS = STR$(YMINS)
2520 GOSUB 2610: GOSUB 2660 'DEFINE FUNCTION TO CALC COORD IN PIXELS
2530 RETURN
2540
2550
2600 ' **** FN TO CALCULATE Y IN SCREEN PIXELS ****
2610 DEF FNPIXY(VAR, YMIN, YMAX, DYPIX, YPIX0) = (VAR - YMIN) * DYPIX / YMAX + YPIX0 + DYPIX
2620 RETURN
2630
2640
2650 ' **** FN TO CALCULATE X IN SCREEN PIXELS ****
2660 DEF FNPIXX(XVAR, XMIN, XMAX, DXPIX, XPIX0) = (XVAR - XMIN) * DXPIX / XMAX + XPIX0
2670 RETURN
2680
2690
2700 ' *** PLOT OR PRINT DATA ***
2710 IF INKS < > "L" THEN IF INKS < > "I" THEN 2740
2720 IF FLO$ = "L" THEN 2780
2730 FLO$ = "L": GOSUB 2500: GOSUB 4500: RETURN 'LIST DATA TO CURRENT !
2740 IF OCSETS = INACTS THEN 2780
2750 IF INKS < > "I" THEN IF INKS < > "P" THEN 2770
2760 IF FLO$ = "P" THEN 2800
2770 FLO$ = "P": GOSUB 2500: GOSUB 4500: RETURN 'PLOT DATA TO CURRENT !
2780 IF FLO$ = "L" THEN PRINT LACK: X2(I), Y2(I), X4(I): RETURN 'TO MAIN PROGRAM
2790 IF OCSETS = INACTS THEN 2840
2800 IF PLOTs = "T" THEN XP = FNPIXX(XI, XMIN, XMAX, DXPIX, XPIX0)
2810 IF PLOTS = "T" THEN XP = FNPIXX(XI, XMIN, XMAX, DXPIX, XPIX0)
2820 IF ABS(XI) > 10000 THEN 2640 'OUT OF RANGE
2830 IF VUTS = "Y" THEN YPR = FNPIXY(YPR, YMIN, YMAX, DYPIX, YPIX0)
2840 IF ABS(YPR) > 10000 THEN 2840
2850 IF VSET(XP, YP) = "PLOTS RHO POINT" THEN 2870
2860 IF VSET(XP, YP) = "PLOTS RHO POINT" THEN 2870
2870 IF THRM$ = " " THEN GOTO 2840
2880 LOCATE 1, 7: PRINT *" = * INT(T) * K *
2890 LOCATE 1, 1: 2840 RETURN 'TO MAIN PROGRAM
2850
2860
2900 ' *** REFRESH PLOT OR DATA UP TO CURRENT POINT ***
2900 CLE: GOSUB 3150: GOSUB 3300 'DRAW AND LABEL AXIES
2920 FOR J = 1 TO 1
2930 IF PLOts = "T" THEN XP = FNPIXX(XI, XMIN, XMAX, DXPIX, XPIX0)
2940 IF PLOTS = "T" THEN XP = FNPIXX(XI, XMIN, XMAX, DXPIX, XPIX0)
2950 IF ABS(XI) > 10000 THEN 2790 'OUT OF RANGE
2960 YP = FNPIXY(YPR, YMIN, YMAX, DYPIX, YPIX0)
2970 IF VUTS = "Y" THEN YPR = X2(I)/RATIO
2980 IF VUTS = "Y" THEN YPR = X2(I)/RATIO
2990
2945 IF ABS(YP)>10000 THEN 2970
2950 'CIRCLE (XP,YP),3
2960 PSET (XP,YP)
2965 IF VYR=**"Y"** THEN PSET (XP,YPR)
2970 NEXT J
2975 IF GCOMP<=**"** THEN RETURN
2976 IF GCSETS=**"ACTS"** THEN GOSUB 5920 ' PLOT COMPARISON DATA
2990 RETURN
3000 '
3010 '**** PRINT DATA ON SCREEN ****
3020 SCREEN 0:CLS
3030 J1=-1:20: IF J1<0 THEN J1=1
3040 FOR J=J1 TO 1
3050 PRINT J:X(0)+Y(0):Y(0)+X(0)
3060 NEXT J
3070 RETURN
3120 '**** SUB TO DRAW GRAPH AXES ****
3130 SCREEN 9 'HI RES GRAPHICS SCREEN
3140 CLS
3150 ISHT (80,15)
3160 DWN=300:RGB=550: TICKU=30: TICKR=55: ZERO=0
3170 FOR J=1 TO 5: DRAW D=TICKU, NM=550, Y*: NEXT J '---LEFT VERT AXIS
3180 FOR J=1 TO 5: DRAW W=TICKR, NM=0,-500*: NEXT J '---BOTTOM HORIZ AXIS
3190 DRAW U=DWN, L=RGB, "**
3200 RETURN
3240 '**** SUB TO LABEL AXES ****
3250 IF LEN(XS)>60 THEN XS=LEFTS(XS,5,60) 'TRUNCATE IF TOO LONG
3260 TIX=((XS,9)
3270 LOCATE 24,XAX. PRINT XAX;
3280 IF LEN(YS)>9 THEN YS=LEFTS(YS,9,4) 'TRUNCATE IF TOO LONG
3290 TAX=-5.5*LEN(YS)
3300 LOCATE 12,YAX. PRINT YAX;
3310 IF LEN(YS)>9 THEN YS=LEFTS(YS,9,4)
3320 TAX=-5.5*LEN(YS)
3330 LOCATE 13,YAX. PRINT YAX;
3340 IF LEN(TS)>70 THEN TS=LEFTS(TS,70) 'TRUNCATE IF TOO LONG
3350 TAXE=-4.5*LEN(TS)
3360 LOCATE 1,YAX. PRINT TS;
3370 LOCATE 24,12-LEN(XMINS):PRINT XMINS,
3380 IF XMINS="" THEN 3460
3390 LOCATE 24,11-LEN(XMINS):PRINT XMINS,
3400 LOCATE 24,10-LEN(YMINS):PRINT YMINS,
3410 LOCATE 24,9-LEN(YMINS):PRINT YMINS,
3420 RETURN
3490 '
3500 '**** SUB TO CHECK KEYBOARD STATUS ****
3510 IN$=INKEY$,
3570 IF IN$="**" THEN RETURN
3580 IF IN$=CHR(13) THEN DATAFLAG=1: GOTO 3710 'MANUAL DATA STORAGE
3590 INK$=IN$,
3600 IF INK$<"Q" AND INK$<"*" THEN 3675
3610 IF DNMS="" THEN 3625 'DATA FILENAME
3620 CLOSE #1: SCREEN 0: GOSUB 6000 '---WRITE DATA TO FILE IN STD FORMAT
3625 PRINT #2,"OUTPUT","PADD$";FON $ '--- turn off current
3630 SCREEN 0: INPUT 'ANOTHER DATA SET? (Y/N):". ANS$,
3640 IF ANS$="Y" OR ANS$="" THEN 3670
3650 ON ERROR GOTO 0 'DISABLE ERROR TRAPPING
3655 PRINT #2,"LOCAL","PADD$"
3660 CLS: END
3670 CLOSE:RETURN 240 'TO MAIN PROGRAM AT MENU
3675 IF INK$="G" OR INK$="*" THEN FLS$="L": FIXITS="NO" : GOSUB 2250
3680 '**** SUB TO CHECK KEYBOARD STATUS ****
3690 IN$=INKEY$,
3750 IF IN$="**" THEN RETURN
3760 IF IN$=CHR(13) THEN DATAFLAG=1: GOTO 3710 'MANUAL DATA STORAGE
3770 INK$=IN$,
3780 IF INK$<"Q" AND INK$<"*" THEN 3870
3790 IF DNMS="" THEN 3725 'DATA FILENAME
3800 CLOSE #1: SCREEN 0: GOSUB 6000 '---WRITE DATA TO FILE IN STD FORMAT
3805 PRINT #2,"OUTPUT","PADD$";FON $ '--- turn off current
3810 SCREEN 0: INPUT 'ANOTHER DATA SET? (Y/N):". ANS$,
3820 IF ANS$="Y" OR ANS$="" THEN 3870
3830 ON ERROR GOTO 0 'DISABLE ERROR TRAPPING
3835 PRINT #2,"LOCAL","PADD$"
3840 CLS: END
3850 CLOSE:RETURN 240 'TO MAIN PROGRAM AT MENU
3855 IF INK$="G" OR INK$="*" THEN FLS$="L": FIXITS="NO" : GOSUB 2250
3860 '**** SUB TO CHECK KEYBOARD STATUS ****
3870 IN$=INKEY$,
3930 IF IN$="**" THEN RETURN
3940 IF IN$=CHR(13) THEN DATAFLAG=1: GOTO 3910 'MANUAL DATA STORAGE
3950 INK$=IN$,
3960 IF INK$<"Q" AND INK$<"*" THEN 3970
3970 IF DNMS="" THEN 3925 'DATA FILENAME
3980 CLOSE #1: SCREEN 0: GOSUB 6000 '---WRITE DATA TO FILE IN STD FORMAT
3985 PRINT #2,"OUTPUT","PADD$";FON $ '--- turn off current
3990 SCREEN 0: INPUT 'ANOTHER DATA SET? (Y/N):". ANS$,
3995 IF ANS$="Y" OR ANS$="" THEN 3970
3990 ON ERROR GOTO 0 'DISABLE ERROR TRAPPING
4000 PRINT #2,"LOCAL","PADD$"
4000 CLS: END
4005 CLOSE:RETURN 240 'TO MAIN PROGRAM AT MENU
4005 IF INK$="G" OR INK$="*" THEN FLS$="L": FIXITS="NO" : GOSUB 2250

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367 IF INKS = "G" OR INKS = "g" THEN INKS = "P" : FIXIT$ = "" :gosub 4120
3680 IF INKS < > "P" THEN IF INKS < > "p" THEN return
3690 IF INKS < > "I" THEN IF INKS < > "L" THEN RETURN
3700 RETURN 330 "TO MAIN PROGRAM AT PLT OR PRINT DATA
3710 RETURN 260 "TO MAIN PROGRAM AT TAKE ONE DATUM
3720 "
3730 "** SUB TO INTERPOLATE TEMPERATURES FROM DIODE T. V TABLE ***
3740 IF THNMTS = "" THEN RETURN "TO MAIN PROGRAM
3770 VX1 = VX
3780 NLO = 1 : NIH = NDATA "LOW AND HI INDICES OF TABLE DATA
3790 N = (NIH + NLO) / 2 "INTEGER DIVIDE " TABLE INDEX TO BE COMPARED TO DATUM
3800 IF VX < VX(N) THEN NIH = N : GOTO 3820
3810 NLO = N
3820 IF NIH < > NLO + 1 THEN GOTO 3790
3830 T = (T(NH1) + (VX - VX(NH1) * (T(NHI) - T(NLO)) / (V(NH1) - V(NLO)))
3840 RETURN
3850 "
3860 "** SUB TO READ IN THERM. CALIB DATA ***
3870 IF THNMTS = "" THEN RETURN
3890 THNMTS = THNMTS
3910 PRINT "* Reading in therm. calibration table ***
3910 OPEN ",", -1, THNMTS
3920 INPUT ",", TTHI$ "-TITLE OF DATA SET
3920 INPUT ",", NDAT
3930 FOR J = 1 TO NDAT
3940 INPUT ",", T(J), V(J)
3950 NEXT J
3960 CLOSE ",
4010 RETURN
4020 "
4050 "** PRINT MESSAGE AT BOTTOM OF SCREEN ***
4060 IF CSGET$ = "ACTS THEN 4090
4070 CLS : LOCATE 25, 1 : PRINT "PRESS: <C/R> STORE PT. <Q> QUIT <G> GRAPHICS;";
4080 LOCATE 1, 1 : GOTO 4110
4090 LOCATE 25, 1 : PRINT "PRESS: <C/R> STORE PT. <Q> QUIT <P> PLOT RESTORE <L> LIST <G> GRAPHICS;"
4110 LOCATE 24, 1
4120 RETURN
4130 "
4150 "** READ IN SETUP AND GRAPHICS PARAMETERS ***
4160 IF PULS$ = "" THEN RETURN
4170 OPEN ",", 1, PULS$
4180 PRINT "** RETRIEVING PARAMETERS FROM ": PULS$,
4190 "--SETUP PARAMETERS
4200 INPUT ",", SFILS$
4210 INPUT ",", SCALEX
4220 INPUT ",", SCALEY
4230 INPUT ",", SCALI
4240 INPUT ",", DEL
4250 INPUT ",", DEL
4260 INPUT ",", DEL
4270 INPUT ",", DUMS$
4280 INPUT ",", NFILT

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4290 INPUT #1, GSETS
4300 INPUT #1, PLOTS$  
4306 INPUT #1, RATIO
4307 INPUT #1, YUITS
4310 INPUT #1, XMIN, XMAX
4310 INPUT #1, YMIN, YMAX
4310 INPUT #1, X$  
4340 INPUT #1, Y$  
4350 INPUT #1, Y2$  
4360 INPUT #1, T$  
4370 '---GPIB & METER PARAMS
4380 INPUT #1, XADDR$  
4390 INPUT #1, YADDR$  
4400 INPUT #1, MX$  
4410 INPUT #1, MY$  
4420 INPUT #1, NXM, NYM
4430 '---COMPARISON GRAPHICS DATA FILE INFO
4440 INPUT #1, GCOMFLS$ DATA FILENAME
4450 INPUT #1, GSETS$ 'FLAG FOR GRAPHICS COMPARISON
4460 INPUT #1, CURRENT$ 'TRANSPORT CURRENT
4470 CLOSE #1
4480 IF GSETS$ = "ACTS" THEN GOSUB 5900: GOSUB 2900 '---READ IN COMP DATA SET
4490 GOSUB 3900 '---READ IN THEM CALIB. DATA
4500 RETURN
4510 '  
4520 '***SAVE SETUP AND GRAPHICS PARAMETERS TO FILE***
4530 IF FSFLS$ = "" THEN RETURN
4540 OPEN "O", #1, PSFLS$  
4550 PRINT**** STORING PARAMETERS TO: "PSFLS" ****
4560 '---SETUP PARAMETERS
4570 PRINT#1, GSETS$  
4580 PRINT#1, PLOTS$  
4590 PRINT#1, RATIO
4600 PRINT#1, YUITS
4610 PRINT#1, XMIN, XMAX
4620 PRINT#1, YMIN, YMAX
4630 PRINT#1, X$  
4640 PRINT#1, Y$  
4650 PRINT#1, T$  
4660 PRINT#1, MX$  
4670 PRINT#1, MY$  
4680 PRINT#1, NXM, NYM
4690 '---GRAPHICS PARAMETERS
4700 PRINT#1, PLOTS$  
4710 PRINT#1, RATIO
4720 PRINT#1, YUITS
4730 PRINT#1, XADDR$  
4740 PRINT#1, YADDR$  
4750 PRINT#1, MX$  
4760 PRINT#1, MY$  
4770 CLOSE #1
4780 RETURN
4790
4800
4850 *** Establish communications with Personal88 ***
4860 OPEN "DEVI8EOUT" FOR OUTPUT AS #2
4870 "Read Personal88"
4880 DOCTL2,"BREAK"
4885 PRINT#,"RESULT"
4890 "Open file to read responses from Personal88"
4900 OPEN "DEVIB8IN" FOR INPUT AS #3
4910 "Enable SEQUENCE error detection by Personal88"
4920 PRINT#,"FILL ERROR"
4930 PRINT#,"TIME OUT 5"
4940 RETURN
4950
4960 *** Read the signon and revision message ***
4970 PRINT#2,"HELLO"
4980 INPUT#3, AS
4990 PRINT AS
5000 RETURN
5010
5050 **** Put the 197's into REMOTE ****
5060 PRINT#2,"REMOTE":YADDR$:
5070 PRINT#2,"REMOTE":XADDR$:
5075 PRINT#2,"REMOTE":PADDR$:
5080 RD: Auto range, N: Execute PC Disable filter TI: Trigger & read
5090 PRINT#2,"OUTPUT":YADDR$;:"RINEX"
5100 PRINT#2,"OUTPUT":YADDR$;:"RINEX"
5110 PRINT#2,"OUTPUT":YADDR$;:"PTIX"
5115 PRINT#2,"OUTPUT":PADDR$:"DROOPIFX"
5116 PRINT#2,"OUTPUT":PADDR$;:"CURRS;"FIX;" turn on current
5120 RETURN
5130
5140
5150
5200 *** Find the average of Nav readings ***
5210 SUMX=0: SUMY=0: VERI=0: SUMX4=0
5212 FOR J=1 TO 2
5214 IF I=1 THEN PRINT#2,"OUTPUT":PADDR$;:"CNEB5S;"FIX;" - curr
5216 IF I=2 THEN PRINT#2,"OUTPUT":PADDR$;:"CURRS;"FIX;" + curr
5218 FOR J=1 TO 10: NEXT J1: time delay
5220 FOR J=1 TO NFILT
5223 PRINT#2,"OUTPUT":YADDR$;:"PIX" Uses front panel range
5225 FOR J=1 TO JD: NEXT J1: time delay
5230 PRINT#2,"ENTER":YADDR$:
5235 INPUT#3, RS: VALX=VAL(MIDS(RS,NXMS))
5240 IF ABS(VALX) > 100 THEN GOSUB 5350: GOTO 5210 "--START OVER"
5245 IF I=1 THEN SUMY=SUMY-VALX ELSE SUMY = SUMY+VALX
5246 NEXT J
5247 NEXT I
5248 SUMX=0: SUMY=0: VERI=0: SUMX4=0
5250 PRINT#2,"OUTPUT": YADDR$; "RINEX" --Uses X-scanner channel # 1
5252 FOR J=1 TO JD: NEXT J1: time delay
5255 PRINT#2,"ENTER":XADDR$:
5260 INPUT#3, RS: VALX=VAL(MIDS(RS,NXMS))
5265 IF ABS(VALX) > 100 THEN GOSUB 5350: GOTO 5210 "--PARTIAL RESTART"
5269 SUMX=ABS(VALX) "DOES NOT filter the thermometer readings !
5270 FOR J=1 TO 2
5271 IF I=1 THEN PRINT#2,"OUTPUT":PADDR$;:"CNEB5S;"FIX;" - curr
5272 IF I=2 THEN PRINT#2,"OUTPUT":PADDR$;:"CURRS;"FIX;" + curr
5273 FOR J=1 TO 10: NEXT J1: time delay
5274 FOR J=1 TO NFILT
5275 PRINT#2, "OUTPUT":XADDR$; "RINEX" --Uses X-scanner channel # 3
5277 FOR J=1 TO JD: NEXT J1: "Time Delay for Auto Range Chg.
5280 PRINT#2,"ENTER":XADDR$:
5285 INPUT#3, RS: VALX=VAL(MIDS(RS,NXMS))
5287 PRINT#2, "OUTPUT":XADDR$; "RINEX" --Uses X-scanner channel # 4
5288 FOR J=1 TO JD: NEXT J1: "Time delay
5290 PRINT#1, "ENTER"; xaddr3
5293 INPUT#1, x: VAL(x) = VAL(MID$(x$5, 1))
5295 IF x = 1 THEN SUMX2 = SUMX2 + VAL(x$2) ELSE SUMX2 = SUMX2 + VAL(x$2)
5300 SUMY4 = SUMX4 + ABS(VAL(x$4))
5302 PRINT1, "OUTPUT"; xaddr3; "R002X"; "--Uses X-scanner channel #2
5303 FOR j = 1 TO j1: NEXT j1
5304 PRINT#1, "ENTER"; xaddr3
5306 INPUT#3, ver: VAL(x) = VAL(MID$(x$3, 1))
5307 IF abs(ver) > 10 THEN GOSUB 5350: GOTO 5240: "--PARTIAL RESTART
5308 IF x1 = 1 THEN VERI = VERI + VERI ELSE VERI = VERI + VERI
5310 NEXT J
5312 NEXT L
5320 SUMX2 = ABS(SUMX2 / (2 * Nfilt)); SUMY = SUMY / Nfilt; VERI = ABS(VERI / (2 * Nfilt))
5325 SUMX4 = SUMX4 / (2 * Nfilt); SUMY = SUMY / 2  "correct for + & - data sets
5330 RETURN
5340
5350 "*** PRINTOUT MESSAGE FOR BAD READING ***
5360 PRINT CHR$(7); "---** BAD READING: \"** //x$5
5370 RETURN
5390
5400 "*** ERROR TRAPPING ***
5410 PRINT "CHR$(7); "---**Bell to indicate error";
5420 IF "ERR" < 5 THEN "RESUME 290"; "---Try to take more data
5425 PRINT" > > BAD FILENAME < < " FOR J = 1 TO 100: NEXT J: RESUME 290
5440
5450
5500 "*** INCREMENT EXTENSION ON DATA FILENAME ***
5510 PRINT "CHR$(7)
5520 IF "DNM$" = "" THEN RETURN
5530 FOR j = 1 TO len("DNM$") IF MID$("DNM$, j) < > ": " THEN NEXT j
5540 j = len("DNM$") + 1
5550 ext = rights("DNM$, j - 1)" DNMS = lefts("DNM$, j - 1)
5560 ext = "EXT = VAL(rights(ext$1) = 1)
5570 exts = rights(exts) " + 1
5580 exts = lefts(exts) + 1
5590 DNMS = DNMS + exts
5600 RETURN
5610
5900 "*** READ IN DATA SET FOR GRAPHICS COMPARISON ***
5905 PRINT*** "RETRIEVING COMPARISON DATA SET *****
5910 IF "GCOMFLS" = "" THEN RETURN
5920 OPEN"; "#1, "GCOMFLS"; "---Title of file data
5930 INPUT#1, ndata
5935 xmn = x(1); ymn = y(1); ymn = y(1)
5940 FOR j = 1 TO NDATG
5950 INPUT#1, xjg, yjg, xjg, yjg
5952 IF "PLTS" = "1" GOTO 5882
5953 IF xjg > xmn THEN xmn = xjg: GOTO 5857
5956 IF xjg < xmn THEN xmn = xjg
5957 IF yjg > ymn THEN ymn = yjg: GOTO 5860
5958 IF yjg < ymn THEN ymn = yjg
5960 NEXT J
5970 CLOSE #1
5975 PRINT "XMIN: " XMIN, XMAX: " XMAX
5976 PRINT "YMIN: " YMIN, YMAX: " YMAX
5980 RETURN
5982 IF xjg > xmn THEN xmn = xjg: GOTO 5857
5984 IF xjg < xmn THEN xmn = xjg
5986 GOTO 5857
5990
5990 "*** PLOT OF COMPARISON DATA ***
5990 CLS: GOSUB 3150: GOSUB 3300 "DRAW AND LABEL AXES
5990 FOR J = 1 TO NDATG
6000
5930 IF PLOTS = "T" THEN XP = FNXPX(XG(0), XMIN, XRGX, DXPX, XPIX0)
5932 IF PLOTS = "H" THEN XP = FNXPX(XG(4), XMIN, XRGX, DXPX, XPIX0)
5945 IF ABS(XP) < 1000 THEN 5970 "OUT OF RANGE!
5949 YP = FNYPY(YG(0), YMIN, YRGY, DYPY, YPIX0)
5949 IF ABS(YP) < 1000 THEN 5970
5950 CIRCLE(XP, YP), 1
5950 TSET (XP, YP)
5970 NEXT J
5980 RETURN
5990 **
6000 **** REWRITE DATA TO FILE AFTER INTERPOLATING TO USER SPECIFICATIONS ****
6002 LOCATE 24.1
6003 IF DNMS = "*" THEN RETURN
6010 NP = 1 "NO. OF DATA POINTS IN SET
6015 OPEN "O", #1, DNMS
6020 PRINT #1, TITLE$;
6025 PRINT #1, NF "No. data points in set
6030 INPUT "Do you wish to sort data according to temperature <Y = Yes> ? " ; RS$
6035 IF RS$ = "Y" THEN PRINT "**** STORING SORTED DATA TO FILE ****" ; GOTO 6075
6040 IF RS$ = "N" THEN PRINT "**** STORING DATA ARRAY DIRECTLY TO FILE ****" ; GOTO 6075
6045 PRINT "**** STORING DATA ARRAY DIRECTLY TO FILE ****
6050 FOR J = 1 TO NP
6055 PRINT #1, X(J); X2(J); Y(J); X4(J)
6060 NEXT J
6065 CLOSE#1
6070 RETURN
6075 PRINT ; LOCATE 24.1 ; PRINT "Percentage Completed: ";
6076 FOR I = 1 TO NP
6077 COMPL = INT(100 * (UNP(I) / NP)) + .5
6079 LOCATE 24, 23 ; PRINT COMPL;
6080 TMP = X(I) ; JP = 1
6085 FOR J = 1 TO NP
6090 IF TMP > X(J) THEN TMP = X(J) ; JP = J
6095 NEXT J
6100 PRINT #1, X1(J); X2(J); Y(J); X4(J)
6105 IF I = 1 THEN TMIN = X1(I)
6110 IF I = NP THEN TMAX = X1(J)
6115 X1(J) = 9999999!
6120 NEXT J
6125 CLOSE#1
6130 FOR I = 1 TO 500
6135 X(I) = 0 ; X2(I) = 0 ; Y(I) = 0 ; X4(I) = 0
6140 NEXT I
6145 IF THNMS = "*" THEN RETURN
6150 PRINT ; PRINT "Tmin = " TMIN " & Tmax = " TMAX ; PRINT
6155 INPUT "Do you wish to interpolate temperatures <Y = Yes> ? " ; RS$
6160 IF RS$ = "Y" GOTO 6170
6165 IF RS$ = "N" THEN 6170 ELSE RETURN
6170 INPUT "Enter Tmin, Tmax & T-interval for data interpolation: " TMIN TMAX DLT
6175 NN = INT(1 + (TMAX - TMIN) / DLT) "No. of data points to interpolate
6180 IF NN > 500 THEN PRINT "Too Many Data Points!" ; BEEP : GOTO 6170
6185 IF TMIN > TMAX THEN PRINT "Try Again!" ; BEEP : GOTO 6170
6190 PRINT "Interpolating Data for Output..." ; PRINT
6192 LOCATE 24.1 ; PRINT "Percentage Completed: ";
6195 FOR J = 1 TO NN
6200 COMPL = INT(100 * (HN(I) / NN)) + .5
6202 LOCATE 24, 23 ; PRINT COMPL;
6205 TMP = TMIN + DLT * (J - 1)
6205 OPEN #1, #1, DNMS
6210 PRINT #1, TITLE$;
6215 INPUT #1, NF
6220 T2 = 0 ; HALL2 = 0 ; RHO2 = 0 ; RMAG2 = 0
6225 K = 1 "Do-Loop to find nearest temp=TMP
6230 T1 = T2 ; HALL1 = HALL2 ; RHO1 = RHO2 ; RMAG1 = RMAG2
6235 INPUT #1, T2, RHO2, HALL2, RMAG2
6240 IF T2 < TMP THEN IF K < NP THEN K = K + 1 : GOTO 6330
6245 CLOSE#1
6245 PRINT #1, NF & X2(I) = X2(I) WHERE NN
Appendix B. Critical Current Acquisition Program

10 DEFINT I-N
20 ' 
30 ' JaTHIEAS *** "Jeathieas" is determination, using K-228 Power Supply
31 ' 
40 ' KEITHLEY 570 SYSTEM ***
50 ' PERSONAL488 DATA ACQUISITION ***
100 ' X-VOLTAGE(I) IS STEPPED, AS CONTROLLED BY K-228 Power Supply
105 ' Program operates digital Power Supply in Current-limited mode with 10% spare V
106 ' K-228 mini step is 1/1000 of any Full Range V: 1, 10, 1 0.1, 1, 10
107 ' There is provision (Menu step 10) for manual search for -Ic
110 ' ACQUIRED X1, X2, X4 AND Y DATA UPON SPECIFIED Y-VOLTAGE CRITERIA.
111 ' X1 @ #1, 2 & 4 rear inputs of X-meter. #2 = Sam-currstdR, #4 = Mag curr;plot-X
112 ' #1 = Thermometer: This gets converted to TK; Mag curr = plot-X
120 ' DATA STORED TO ASCII FILE. FLOATS AUXILIARY DATA FILE FOR COMPARISON
125 ' COMMAND P0 SENT TO Y-DVM (FOR K-111 TURNS OFF DIGITAL FILTERING)
130 ' JCH = Meas Jc(Ic) vs H (Image/Scalaram). With no cooling pauses (lip)
135 ' # It is interpolated between last below-Vc & 1st above-Vc read of J.
136 ' *** waits after ca recorded pt for input new Xinc or use ppgm value.
140 ' ** AUTO mode available. Set AUTODATA #1 for continuous recording per ppgm
145 ' > > > * * Now uses + & - curr, with minimum switching of K-228
150 ' * note that Like old JeZ, this has delta as fraction of x.
155 ' # * Saves avg std dev of Ic calc'd from extrapolated H&Lo err limits.
160 ' # when V> Vc on 1st pass then stores I, Vc, Ic, H, not. Ic, and Vc, ead, T
165 ' *** TWO RANGE: Now has a low current output mode (MODES="L") allowing
170 ' 1 uA < 1 x 10 mA operating range. This is achieved by
150 ' use of a 1000 ohm std. resistor and utilization of the
151 ' voltage limit mode of the K-228...
152 ' Maintains Temperature Controller Set Point to values based upon user
153 ' input and current sample temperature (optional).
154 '**** MAIN PROGRAM ***
155 '**** DEFINE DEFAULT PARAMETERS ***
156 'CLS: KEY OFF: KEY 1,"LIST 200-400"+CHR$(13)
157 'DEFINT I-N
158 'DIM X(500),Y(500),Z(500),X(500),Q(500),Y(500)
159 'DIM V(200),T(200)
160 'PRINT "_PROGRESSIVE""1P=PRINT""" 
161 'DIM VO(200),T(200),"ARRAY FOR THEHM. CALIBRATION TABLE(e.g. DIODE V,T)
162 'DIM X(500),Y(500),Z(500),X(500),Q(500),Y(500)
163 'COMPARISON DATA FOR GRAPHICS
164 'ON ERROR GOTO 5400 "ERROR TRAPPING
165 'RESTORE 470
166 'DATA 10,1,2,1,0,1,1,1,1
167 'READ CUR,SCALEX,RCIRC,SCALEY,DEL,DLY,GO%,GI%,NFILT,SCALEZ"Defaults"
168 'DATA "<INACTIVE>"","<ACTIVE>
169 'READ INACTS,ACTS; GETS="INACTS": GCSETS="INACTS": TSETS="INACTS"
170 'DIM PBUS ADDRESSES & METER PARAMS
171 'DIM X(500),Y(500),Z(500),X(500),Q(500),Y(500)
172 'K$="KEITHLEY 181/195/197" "GB BUS ADDRESSES & METER PARAMS
173 'EPS="$Kolesky 221 Power Supply"
174 'DATA "$","",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",",","
510 '  
520 "GRAPHICS DEFAULT PARAMETERS"  
530 RESTORE 510  
540 READ XMIN,XMAX,YMIN,YMAX  
550 DATA 0.1,0.1,0  
560 READ X$,Y$,THETA,T,S  
570 RESTORE 590  
580 READ XS*,Y*,T*,S*  
590 DATA *X-AXIS(UNITS)*, *Y-AXIS* (UNITS)*, "TITLE OF GRAPH"  
600 RESTORE 620  
610 READ DX, DY, X0, X1, Y0, Y1 *AXIS CONTANTS IN PIXELS  
620 DATA 550,300,30,15  
630 RETURN "TO MAIN PROGRAM"  
640 '  
650 '  
700 "*** SIGN-ON HARDWARE SETTINGS MESSAGE ***"  
710 CLS: PRINT CHR$(7)  
720 PRINT: PRINT " *** HARDWARE SETTINGS ***"  
730 PRINT " * 1. X-INPUT: GPIB Address: \*:XADDR:; Meter ID: \*:XM$"  
740 PRINT " * 2. Y-INPUT: GPIB Address: \*:YADDR:; Meter ID: \*:YM$"  
747 PRINT " * 3. P-INPUT: GPIB Address: \*:PADDR:; Par Supp ID: \*:MP$"  
750 PRINT:PRINT  
752 PRINT " * Meter Setup: X channel #1 < === > Thermometer Voltage Signal"  
754 PRINT " * X channel #2 < === > Sample Current Std. Resistor*"  
755 PRINT " * X channel #3 < === > Sample Heat Dissipation Signal"  
756 PRINT " * X channel #4 < === > Magnet Curr. 1/100 Ohm Resistor*"  
757 PRINT " * Y voltmeter < === > Sample Voltage *PRINT"  
759 PRINT " * Reset DRC-9/1C & Set GPIB address to \*:TADDR: - PRINT"  
760 INPUT*ENTER SELECTION # (C/R) TO CONTINUE: \*:JCODE"  
770 ON CODE: GOTO 790,810,840  
780 RETURN "TO MAIN PROGRAM"  
790 INPUT*ENTER NEW GPIB ADDRESS FOR X-INPUT: \*:XADDR"  
791 CUSUB 850 "-- METER ID CHOICES FOR READING STRING MASKING"  
792 INPUT*ENTER X-INPUT METER ID CODE (DEFAULT = PREVIOUS): \*:NMT"  
794 IF NMT < 0 THEN NM=NMT ELSE 100  
795 CUSUB 900: NM$=MS: NNM$=NM$ -- ASSIGN METER ID NAME & MASKING DATA  
800 YADDR=STR$(YADDR): GOTO 720  
810 INPUT*ENTER NEW GPIB ADDRESS FOR Y-INPUT: \*:YADDR"  
811 CUSUB 850 "-- METER ID CHOICES"  
812 INPUT*ENTER Y-INPUT METER ID CODE (DEFAULT = PREVIOUS): \*:NMT"  
814 IF NMT < 0 THEN NM=NMT ELSE 120  
816 CUSUB 900: NY$=MS: NNM$=NM$ -- ASSIGN METER ID NAME & MASKING DATA  
820 YADDR=STR$(YADDR): GOTO 720  
840 INPUT*ENTER NEW GPIB ADDRESS FOR P-INPUT: \*:PADDR"  
841 CUSUB 850 "-- METER ID CHOICES"  
842 INPUT*ENTER P-INPUT METER ID CODE (DEFAULT = PREVIOUS): \*:NMT"  
843 IF NMT < 0 THEN NM=NMT ELSE 148  
844 CUSUB 900: MP$=MS: NNM$=NM$ -- ASSIGN METER ID NAME & MASKING DATA  
848 PADDR=STR$(PADDR): GOTO 720  
849 '  
850 "*** ASSIGN STRING MASKING PARAMS FOR METERS ***"  
854 PRINT "*** Meter ID Codes ***"  
855 PRINT " 1: KEITHLEY 181,199,197"  
856 PRINT " 2: FLUKI 8940A"  
857 PRINT " 3: Keithley 228 Prep Supp"  
860 RETURN  
870 '  
880 '  
890 '  
900 "*** ASSIGN METER ID NAME ***"  
901 ON NM GOTO 930,940,950  
920 PRINT CHR$(7): PRINT " < < WRONG METER ID > > ": RETURN 130  
930 MS= "KEITHLEY 181/199/197": NMSK=5: RETURN  
940 MS= "FLUKI 8940A": NMSK=1: RETURN  
950 MS= "KEITHLEY 228 Prep Supp": NMSK=1: RETURN  
960 '  
1000 SCREEN 0: CLE: BMS$=""  
1100 ""
1010 GOSUB 5500 'INCREMENT EXTENSION ON DATA FILENAME
1020 PRINT: PRINT *; "SET UP PARAMETERS FOR DA-<EXT>.BAS** *
1030 PRINT *; "FILENAME OF SETUP AND GRAPHICS PARAMETERS TO USE: *.PFLS
1040 PRINT *; "FILENAME OF SETUP AND GRAPHICS PARAMETERS TO SAVE TO: *.PSFLS
1050 PRINT *; "SCALE FACTOR (Signal/Max V or 1/STD chans) : *.SCALEX
1060 PRINT *; "XM/SIGNAL RANGE/(Ampl)STEP SIZE: fraction: *;XMINC;to;XMAXC;*/DELX
1070 PRINT *; "Y-VOLTAGE SCALE FACTOR (Signal/Max V) : *.SCALEY
1080 PRINT *; "Y-SIGNAL LIMIT: *;DLY
1090 PRINT *; "Y-SIGNAL STEP SIZE: *;DELY
1100 PRINT *; "DATA FILENAME: *.DNMS
1110 IF DNMS=** GOTO 1110
1120 PRINT *; "TITLES
1130 PRINT *; "THRM.S CAL. TABLE FILENAME (for X1-signal conversion): *.THNMS
1140 IF THNMS=** GOTO 1130
1150 PRINT *; "HLMIT
1160 PRINT *; "EXIT SELECTION # <C>R> TO EXECUTE; *.CODE
1170 ON ICODE GOTO 1440,1450,1290,1310,1180,1200,1220,1350,1460,1380,1330,1335,1480,1491,1472,1325
1180 RETURN "TO MAIN PROGRAM
1190 GOTO 1020
1200 INPUT *; "ENTER Y-SIGNAL LIMIT: *.DLY
1210 GOTO 1020
1220 INPUT *; "ENTER DATA FILENAME (EXT. DTN WILL BE ADDED IF NOT ENTERED): *.DNMS
1230 IF DNMS=** THEN 1230
1240 PRINT: ENTER 80 CHARACTER DATA SET TITLE DEFAULT = PREVIOUS: * INPUT**.DUMS
1250 IF DUMS=** THEN 1250
1260 TITLES=DUMS
1270 FOR J=1 TO LEN(DNMS); IF MID$(DNMS,1,1)>* THEN NEXT J ELSE 1280
1272 DNMS = DNMS + *;DTN
1280 GOTO 1020
1290 INPUT *; "ENTER X-VOLTAGE SCALE FACTOR (Signal/Vmax or 1/STD chans): *.SCALEX
1300 GOTO 1020
1310 INPUT *; "ENTER X-SIGNAL RANGE STEP SIZE (XMINC.XMAXC.DELX
1315 INPUT *; "ENTER X-SIGNAL BACKSTEP (Backstep of fraction of Xmax): *.XOFFC
1320 GOTO 1020
1325 INPUT *; "ENTER MAXIMUM HEATING ALLOWED (mW): *.HLMIT
1330 GOTO 1020
1335 GOSUB 4550: END 'STORE PARAMS TO FILE AND EXIT
1340 GOTO 1020
1350 INPUT *; "ENTER THERM.CALIB. TABLE FILENAME (EXT.CAL WILL BE ADDED): *.THNMS
1360 IF THNMS=** THEN 1360 ELSE THNMS=THNMS*;CAL
1370 GOSUB 3900 'READ IN THERM. CALIB. DATA
1380 INPUT *; "ENTER VOLTAGE SCALE FACTOR (signal/voltage): *.SCALEZ
1390 GOTO 1020
1395 INPUT *; "ENTER NO. SAMPLES IN DIGITAL FILTERING: *.PFILT
1400 GOTO 1020
1405 INPUT *; "ENTER FILENAME FOR SETUP PARAMETERS TO USE (EXT. PAR WILL BE ADDED): *.PFLS
1410 IF PFLS=** THEN 1410 ELSE PFLS=PFLS*;PAR
1420 GOSUB 4150: GOTO 230 'READ IN SETUP AND GRAPHICS PARAMETERS
1430 INPUT *; "ENTER FILENAME FOR SETUP PARAMETERS TO SAVE TO (.PAR WILL BE ADDED): *.PSFLS
1440 IF PSFLS=** THEN 1440 ELSE PSFLS=PSFLS*;PAR
1450 GOTO 1020
1460 INPUT *; "ENTER TEMPERATURE INTERVAL BETWEEN DATA: *.DLY
1470 GOTO 1020
1472 IF THNMS = "" THEN PRINT " Enter a temperature calibration file if you plan to use the controller"; GOTO 1020
1473 IF TSE$T$=ACT$S THEN TSE$T$=INACT$S: GOTO 1020
1474 PRINT " Temperature Controller Settings": TSE$T$=ACT$S
1475 INPUT * " Enter Time, Time & Vsp-Samp Set Pointer": TC1,Tc2,TCDEL
1476 IF TC1>Tc2 OR Tc2>320 OR Tc1<0 THEN PRINT " Bad Entry!": GOTO 1475
1477 GOTO 1020
1480 GOSUB 7000 * Check out circuit resist with new STD
1490 GOTO 1020
1491 INPUT * ENTER OPERATING RANGE (H, > |mA|; L, < |mA|): *.MODES
1492 IF MODE$ = "H" THEN GOSUB 1800; GOTO 1020
1493 IF MODE$ = "L" THEN GOSUB 1810; GOTO 1020
1494 PRINT "Error": BEEP; GOTO 1491
1495
1496
1500 *** OPEN DATA FILE ***
1510 IF DNMS="" THEN 1550
1520 OPEN "O",#,DNMS
1530 PRINT #1, "TITLE"
1540 PRINT #1," (A) H(kOhm) Heating(mW) Devt(V) "
1550 RETURN
1560
1570
1600 *** INITIALIZATION FOR DATA ACQU. ***
1610 CLOSE ""--close any open files
1620 GOSUB 4050 --PRINT MESSAGE AT SCREEN BOTTOM
1630 1=0 "INITIALIZE DATA ARRAY INDEX"
1640 GOSUB 4850 -- ESTABLISH COMMUNICATION W/PERSONAL48
1650 GOSUB 4950 -- SIGNON MESSAGE
1660 GOSUB 5050 --ASSIGN REMOTE MODE ADDRESSES
1670 GOSUB 5790 -- INITIALIZE FOR ANALOG OUTPUT --not used here
1680 FLO$ = "L" --INITIALIZE FOR DATA SCREEN PRINTOUT
1690 GOSUB 1500 -- OPEN DATA FILE
1700 ADAT=1 ' Key switch for AUTODATA control via KB
1701 PVXFLG=0 ' -- FLAG FOR FIRST TIME THRU
1702 PRINT " *** Beginning Data Acquisition ***"
1703 PRINT " " # (A) H(kOhm) Heating(mW) Devt(V) next 1"
1710 RETURN "TO MAIN PROGRAM"
1720
1730
1750 *** TAKE DATA SAMPLE ***
1760 DQBP INPUT ==
1770 EMST?$ = 100*(DELY/SCALE$) * allowed safety limit for sample voltage
1775 GOSUB 6400 -- FIND AVG OF INFILT READINGS using K-228 +/- & min switching
1780 VX = ABS(SUMX*SCALE$)/VY = ABS(SUMY*SCALE$); VZ = ABS(SUMZ*SCALE$); DXY = XY/SCALE$;
1781 SCALEMAG = 102.91 ' -- to convert Mag Curr (Hall crystal) with .01 std
1782 VM = ABS(SUMM$*SCALEMAG) ' -- Mag field in kG
1783 IF HPAT$ > HLIMIT 8.000 ' Excessive Heating Detected
1785 RETURN "TO MAIN PROGRAM"
1800 SOUND 880, 15
1801 INPUT * REMOVE 1 kOhm Std. Resistor at K-228 Output then Press RTN", DUMS$
1803 IF DELXC < .0001 THEN DELXC = .0001
1805 RETURN
1810 SOUND 880, 15
1815 INPUT * INSTALL 1 kOhm Std. Resistor at K-228 Output then Press RTN", DUMS$
1817 IF DELXC < .000001 THEN DELXC = .000001
1820 RETURN
1830
1840
1850 *** DATA TEST FOR OUTPUT ***
1860 IF DATFLG = 0 THEN 1920
1870 IF INKS < 0.00 THEN 1900
1890 PRINT CHK$?; "-- BELL TO INDICATE MANUAL DATA STORAGE
1900 PRINT CHK$?; "-- BELL TO INDICATE MANUAL DATA STORAGE
1910 DATFLG = 0. GOTO 1970 'MANUAL DATA STORAGE
1920 IF VY < DELY THEN VYL$ = Y; VXL$ = V; VLYL$ = DXY; RETURN 295 ' for MORE DATA
1930 BEEP; IF VXL$ = THEN XIC = VX; DA = 1; RETURN 300 ' store data as is, vs,xy, 1.7
1940 DX = VX; VXL$ ' store value interpolated Xc & hi, lo err limits
1945 XIC = (DELY-VYL$)*DX/DY + VXL$ 'Xc is It, DELEY is Yc
162
1947    DIVL=DY+DVY-DVYL: IF DIVL=0 THEN DA=1: GOTO 1970 'Lo lim extaps inf
1948    DIVH=DX-DVX+DVX+DVYL: IF DIVH=0 THEN DA=1: GOTO 1970 'Hi lim extaps inf
1950    XDL=VX+(DX-VX-DELY-DVY)/DIVL. 'Xic lo err lim, from upper Yerr
1955    XDH=VX+(DX-VX-DELY-DVY)/DIVH 'Xic hi err lim, from lower Yerr
1960    XM1=ABS(XDL-XIC)+ABS(XDL-XIC)*.5 'Avg of hi & lo std errs on Xic
1970    VXL=0; YV=.5*(DVX+DVY): RETURN 300 'store: ic.Avg(Yerr),Avg(Err),T,Im
1980
1990
2000  '*** PRINT VALUES ON DISK ***
2010  I=I+1 'INCREMENT INDEX
2015  X(I)=XIC; Y(I)=HEAT; Q(I)=DA 'as found at Test for output (185)
2020  IF THY<1: THEN Z(T)=Y2: GOTO 2040
2030  Z(T)=I 'Temp from interpolt table
2035  XM0=VM 'Mag curr un-converted
2040  IF ENMS=="" THEN 2060
2050  PRINT #1,X(I);XM0;Y(I);Q(I)
2060  RETURN 'TO MAIN PROGRAM
2070
2090
2100  '*** TEST TO REDFINE GLOBAL GAIN ***
2110  IF VSTSM>5 THEN G5=1: GOTO 2150
2120  IF VSTSM>2 THEN G5=2: GOTO 2150
2130  IF VSTSM>1 THEN G5=5: GOTO 2150
2140  G5=10
2150  RETURN
2160  IF VSTSM="" THEN G5=G5: GOSUB 1790: RETURN 'CHANGE TO NEW X-GAIN
2170  GS5=G5: GOSUB 1790 'CHANGE TO NEW Y-GAIN
2180  RETURN
2190
2200
2250  '*** GRAGHICS PARAMETERS ***
2260  GSSETS=ACTS 'SCREEN GRAPHICS ACTIVE
2270  PRINT: PRINT: PRINT: *** SCREEN GRAPHICS PARAMETERS ***
2280  PRINT 1: T-axis Tmin, Tmax, *XMIN,XMAX
2290  PRINT 2: Jc-axis Jemin, Jemax, "YMIN, YMAX
2300  PRINT 3: T-axis label: ",X$'
2310  PRINT 4: Jc-axis label: ",Y1$;Y2$
2320  PRINT 5: Graph Title: ",T$'
2325  PRINT 6: COMPARISON DATA SET FILENAME: *.GCOMFLS
2330  PRINT 7: VIEW COMPARISON DATA SET: *.GCSETS
2335  PRINT
2340  INPUT> ENTER SELECTION # (**CR > TO MAIN MENU): *.ICODE
2350  ON ICOD3 GOTO 2370,2390,2410,2430,2470,2481,2483
2360  GOTO 2490
2370  INPUT> ENTER T-axis Tmin, Tmax, *XMIN,XMAX
2380  GOTO 2270
2390  INPUT> ENTER Jc-axis Jemin, Jemax, *YMIN,YMAX
2400  GOTO 2270
2410  INPUT> ENTER T-axis label: ",X$
2420  GOTO 2270
2430  INPUT> ENTER Jc-axis label: ",Y$
2440  FOR J=1 TO LEN(YS): IF MID$(YS,J,1)<>"(" THEN NEXT J
2445  Y1S=LEFT$(YS,-1): J=LEN(YS)-1+1: Y2S=RIGHT$(YS,J)
2460  GOTO 2270
2470  INPUT> ENTER Graph Title: ",T$'
2480  GOTO 2270
2481  INPUT> ENTER DATA SET FILENAME: *.GCOMFLS
2482  GOSUB 5900: GOTO 2270 'READ IN DATA SET FROM FILE
2483  INPUT> VIEW PLOT OF DATA SET (Y=*YES?): *.ANS$'
2484  IF ANS$="Y" OR ANS$="YES" THEN GSETS=ACTS ELSE GCSETS=INACTS:GOTO2270
2485  GOSUB 4900 'DEFINE GRAPH ANES RANGES
2486  GOSUB 5900 'PLOT DATA SET
2487  GOSUB 4111 'PRINT MESSAGE AT SCREEN BOTTOM
2488  IF INKEYS="" THEN 2488 ELSE SCREEN 0: GOTO 2270
2489
2490  XRNG=XMAX-XMIN; YRNG=YMAX-YMIN

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2500 XMIN = STR$(XMIN); XMAX = STR$(XMAX)
2510 YMIN = STR$(YMIN); YMAX = STR$(YMAX)
2520 GOSUB 2610: GOSUB 2660  'DEFINE FUNCTION TO CALC COORD IN PICALS
2530 RETURN
2540 '  
2550 ' 2600 *** FN TO CALCULATE Y IN SCREEN PIXELS ***
2610 DEF FNYPIXD(YVAR, YMIN, YENG, DYPIX, YPIX0) = (YVAR - YMIN) * DYPIX / YENG + YPIX0 + DYPIX
2620 RETURN
2630 '  
2640 ' 2650 *** FN TO CALCULATE X IN SCREEN PIXELS ***
2660 DEF FNXPXD(XVAR, XMIN, XENG, DXPIX, XPIX0) = (XVAR - XMIN) * DXPIX / XENG + XPIX0
2670 RETURN
2680 '  
2700 ' *** PLOT OR PRINT DATA ***
2710 IF INKS < > "L" THEN IF INKS < > "I" THEN 2740
2720 IF FLOG = "L" THEN 2780
2730 IF FLOG = "I" THEN GOSUB 2600: GOSUB 4050: RETURN 'LIST DATA TO CURRENT
2740 IF FLOG = "L" THEN GOSUB 2600: GOSUB 4050: RETURN 'LIST DATA TO CURRENT
2750 IF INKS < > "P" THEN IF INKS < > "P" THEN 2780
2760 IF FLOG = "P" THEN 2800
2770 PRINT USING "####": "ZT(0);"
2780 PRINT USING "####": "ZT(0);"
2790 PRINT USING "####": "ZT(0);"
2800 PRINT USING "####": "ZT(0);"
2810 PRINT USING "####": "ZT(0);"
2820 PRINT USING "####": "ZT(0);"
2830 PRINT USING "####": "ZT(0);"
2840 PRINT USING "####": "ZT(0);"
2850 RETURN "to MAIN program
2860 ' *** REFRESH PLOT OF DATA UP TO CURRENT POINT ***
2900 CLS: GOSUB 3130: GOSUB 3300  'DRAW AND LABEL AXES
2910 FOR J = 1 TO 1
2920 IF XP < XENG THEN 2840
2930 IF XP > XENG THEN 2840
2940 IF ABS(YP) > 10000 THEN 2840
2950 IF ABS(YP) > 10000 THEN 2840
2960 X = FNYPIXD(XP, YMIN, YENG, DXPIX, XPIX0)
2970 IF XENG > 10000 THEN 2970
2980 Y = FNYPIXD(YP, YMIN, YENG, DYPIX, YPIX0)
2990 IF YENG > 10000 THEN 2970
3000 CIRCLE (XP, YP), 3
3010 NEXT J
3020 RETURN ' *** PLOT COMPARISON DATA ***
3030 RETURN '  
3050 *** PRINT DATA ON SCREEN ***
3060 SCREEN 0: CLS: LOCATE 33, 1.0
3070 PRINT "# "  
3080 PRINT "# "  
3090 PRINT "# "  
3100 PRINT "# "  
3110 PRINT "# "  
3120 PRINT "# "  
3130 PRINT "# "  
3140 PRINT "# "  
3150 PRINT "# "  
3160 PRINT "# "  
3170 PRINT "# "  
3180 PRINT "# "  
3190 PRINT "# "  
3200 PRINT "# "  
3210 PRINT "# "  
3220 PRINT "# "  
3230 PRINT "# "  
3240 PRINT "# "  
3250 PRINT "# "  
3260 PRINT "# "  
3270 PR
3064 PRINT USING "+#####":X(I);  
3065 PRINT USING "+#####":X(M);  
3066 PRINT USING "+#####":Y(J);Q(I);Q(0)  
3160 NEXT J  
3160 RETURN  
3160 '  
3160 '  
3160 **** SUB TO DRAW GRAPH AXES ***  
3160 SCREEN 9 'Hi RES GRAPHICS SCREEN  
3170 CLS  
3170  
3170 IN$(0,15)  
3170 DW$=300: ROT$=550: TICKU$=30: TICKR$=55: ZERO$=0  
3200 FOR J=1 TO 10: DRAW"*"=TICKU$:NM+550,0;*: NEXT J --LEFT VERT AXIS  
3200 FOR J=1 TO 10: DRAW"*"=TICKR$:NM+1,300;*: NEXT J --BOTTOM HORIZ AXIS  
3220 DRAW"U"=DW$,:=ROT$;  
3230 RETURN  
3240 '  
3250 '  
3300 **** SUB TO LABEL AXES ***  
3310 IF LEN(WX$)>60 THEN XM$=LEFT$(WX$,60):TRUNCATE IF TOO LONG  
3320 TAX=44 /*LEN(X)  
3330 LOCATE 24,1:PRINT WX$;  
3340 IF LEN(YI$)>9 THEN YI$=LEFT$(YI$,9) "TRUNCATE IF TOO LONG  
3350 TAX=5.5*LEN(YI$)  
3360 LOCATE 11,TAX;PRINT YI$;  
3370 IF LEN(Y2$I$)>9 THEN Y2$I$=LEFT$(Y2$I$,9)  
3380 TAX=5.5*LEN(Y2$I$)  
3390 LOCATE 13,TAX;PRINT Y2$I$;  
3400 IF LEN(TS$)>70 THEN TS$=LEFT$(TS$,70) "TRUNCATE IF TOO LONG  
3410 TAX=44 /*LEN(TS$)  
3420 LOCATE 1,TAX;PRINT TS$;  
3430 LOCATE 21,12-LEN(XMNS$):PRINT XMNS$;  
3440 IF XMNS$=" " THEN 3460  
3450 LOCATE 23,1-LEN(XMAX$):PRINT XMAX$;  
3460 LOCATE 23,10-LEN(YMNS$):PRINT YMNS$;  
3470 LOCATE 23,10-LEN(YMNS$):PRINT YMNS$;  
3480 RETURN  
3490 '  
3500 '  
3520 '  
3530 **** SUB TO CHECK KEYBOARD STATUS ***  
3540 IN$=INKEY$ "Read Keyboard Buffer....  
3550 IF IN$="Q" THEN INS="Q" "Emergency Stop  
3560 IF INS="": THEN RETURN  
3570 IF INS<"A" AND INS>"*" THEN 3580  
3574 ADAT=.ADAT ' switch status  
3576 IF ADAT<0 THEN AUTODATA =1  
3578 IF ADAT>0 THEN AUTODATA =0  
3530 IF IN$=CHR$(13) GOTO 370 'MANUAL DATA interrupt to revise Xmin  
3590 IN$=IN$  
3600 IF IN$="": AND IN$>"q" THEN 3600  
3610 IF DMNS$="": THEN 3630 'DATA FILENAME  
3620 CLOS#1: GOSUB 6000 '---REWRITE DATA TO FILE IN STD FORMAT  
3630 SCREEN 0: INPUT "ANOTHER DATA SET (Y=YES)?",ANS2$  
3640 IF ANS2$="y" OR ANS2$="Y" THEN 3670  
3650 ON ERROR GOTO 0 'DISABLE ERROR TRAPPING  
3655 PRINT2",LOCAL":;ADD$  
3656 CLS: EIN$  
3660 CLOSE RETURN 240 'TO MAIN PROGRAM AT MENU  
3660 IF IN$="A" THEN AUTODATA =1 : RETURN  
3682 IF IN$="a" THEN AUTODATA =1 : RETURN  
3684 IF IN$="C" GOTO 3720  
3685 IF IN$="c" GOTO 3720  
3687 IF IN$="T" GOTO 3730  
3688 IF IN$="t" GOTO 3730  
3690 IF IN$>"P" THEN IF IN$<">p" THEN RETURN  
3695 IF IN$>"P" THEN IF IN$>">L" THEN RETURN  
3700 RETURN 220 'TO MAIN PROGRAM AT PLT OR PRINT DATA
3710 PRINT " Start Current Test ";
3715 RETURN 340  " to Main Program at input next XCC
3720 INPUT " ENTER OPERATING RANGE (H, >1mA; L, <10mA): ",MODES
3721 xc=xmnc  " set xc to a safe value.
3722 IF MODES= "H" THEN GOSUB 1800; INK$= "L" : RETURN 320
3724 IF MODES= "L" THEN GOSUB 1810: INK$="L" : RETURN 320
3725 PRINT " Error": BEEP: GOTO 3720
3729 PRINT: INPUT " ENTER NEW THERM. CAL. TABLE (EXT.CAL WILL BE ADDED): ",THMS$  
3732 IF THMS$= "" THEN 3690 ELSE THMS$=THMS$+",CAL"
3733 CLOSE#1  " TEMPORARILY CLOSE DATA OUTPUT FILE
3734 GOSUB 3990  " READ IN THERM. CAL. TABLE
3735 OPEN IN#1 FOR APPEND AS #1  " REOPEN THE DATA OUTPUT FILE
3736 INPUT " ENTER NEW SCALE FACTOR (Signal/Voltage): " ,SCALEZ
3738 INK$= "L" : RETURN 320
3740"
3745"
3750 *** SUB TO INTERPOLATE TEMPERATURES FROM DIODE T,V TABLE ***
3755 IF THMS$= "" THEN RETURN TO MAIN PROGRAM
3770 VZC=VZ
3780 NLO=1: NH=N: NDATA= LOW AND HI INDICS OF TABLE DATA
3790 N=(NH+1): NLO= INTEGER DIVIDE TABLE INDEX TO BE COMPARED TO DATUM
3800 IF VZ<V(N) THEN NHE=N: GOTO 3120
3810 NLO=N
3820 IF NH< NLO+1 THEN GOTO 3790
3830 T=(T(NH)+T(V(NH))*T(NH-T(NLO))/(V(NH)-V(NLO))
3840 RETURN
3850"
3860"
3900 *** SUB TO READ IN THERM. CALIB DATA ***
3910 IF THMS$= "" THEN RETURN
3930 THNS$=THMS$  " TEMPORARILY CLOSE DATA OUTPUT FILE
3940 PRINT: *** Reading in therm. calibration table ***
3950 OPEN "T",#1,THNS$  " TITLE OF DATA SET
3960 INPUT #1,NDATA
3970 FOR J=1 TO NDATA
3980 INPUT #1,V(J),T(J)
3990 NEXT J
4000 CLOSE #1
4010 RETURN
4020"
4030"
4050 *** PRINT MESSAGE AT BOTTOM OF SCREEN ***
4060 IF GSETS$=ACTS THEN 4090
4070 CLS: LOCATE 25,1: PRINT"PRESS: RTN= > RESSET_ Q= > QUIT C= > POWER RANGE A= > AUTO on/off  
T= > THERM ";
4080 LOCATE 1,1: GOTO 4110
4090 LOCATE 25,1: PRINT"PRESS: RTN= > SET_ Q= > QUIT P= > PLOT L= > LIST A= > AUTO C= > POWER RANGE  
T= > THERM ";
4100 LOCATE 24,1
4110 RETURN
4111 LOCATE 25,1: PRINT" PRESS < C/R > TO CONTINUE"
4112 LOCATE 24,1
4113 RETURN
4120"
4130"
4150 *** READ IN SETUP AND GRAPHICS PARAMETERS ***
4160 IF PUFIL$= "" THEN RETURN
4170 OPEN "T",#1, PUFIL$  " SETUP PARAMETERS
4180 PRINT: *** RETRIEVING PARAMETERS FROM *.PUFIL$ ***
41900---SETUP PARAMETERS
4195 INPUT #1.PUFIL$  " SETUP PARAMETERS
4200 INPUT #1,SCALEZ
4205 INPUT #1,RCIRC
4207 INPUT #1,XMNC,XMAXC,DELY
4210 INPUT #1,XOFFC
4220 INPUT #1,SCALEY

4210 INPUT #1, DELY
4220 INPUT #1, DNYS$
4230 INPUT #1, TITLES$
4240 DUMS$=TITLES$
4250 INPUT #1, THEN$S$
4260 INPUT #1, SCALEZ$
4270 INPUT #1, DELT$
4280 INPUT #1, NFILT$
4290 INPUT #1, GSET$
4300 '--- GRAPHICS PARAMETERS
4310 INPUT #1, XMIN, XMAX$
4320 INPUT #1, YMIN, YMAX$
4330 INPUT #1, X$S$
4340 INPUT #1, Y1$S$
4350 INPUT #1, Y2$S$
4360 INPUT #1, T$S$
4370 '--- GPIB & METER PARAMS
4380 INPUT#1,XADDR$
4390 INPUT#1,YADDR$
4400 INPUT#1,PADDR$
4410 INPUT#1,MXS$
4420 INPUT#1,MYS$
4430 INPUT#1,NXM,NYM,NPM$
4440 '--- COMPARISON GRAPHICS DATA FILE INFO
4450 INPUT#1, GCCOMLF$ 'DATA FILENAME
4460 INPUT#1, GSET$ 'FLAG FOR GRAPHICS COMPARISON
4470 'DONT INCLUDE MODES
4480 CLOSE#1
4490 GOSUB 3900 '--- READ IN THERM CALIB. DATA
4500 IF GSET$ = ACTS THEN GOSUB 5600: GOSUB 2490 '--- READ IN COMP DATA SET
4510 RETURN
4520 '*
4530 '****SAVE SETUP AND GRAPHICS PARAMETERS TO FILE****
4540 IF PSFLS$ = "" THEN RETURN
4550 OPEN "O", #1, PSFLS$
4560 PRINT**** 'STORING PARAMETERS TO: "PSFLS$": ****
4570 '---SETUP PARAMETERS
4580 PRINT#1, PSFLS$
4590 PRINT#1, SCALEX$
4600 PRINT#1, SCAYE$
4610 PRINT#1, DELY$
4620 PRINT#1, DNYS$
4630 PRINT#1, TITLES$
4640 PRINT#1, THEN$S$
4650 PRINT#1, SCALEZ$
4660 PRINT#1, DELT$
4670 PRINT#1, NFILT$
4680 PRINT#1, GSET$
4690 '--- GRAPHICS PARAMETERS
4700 PRINT#1, XMIN, XMAX$
4710 PRINT#1, YMIN, YMAX$
4720 PRINT#1, X$S$
4730 PRINT#1, Y1$S$
4740 PRINT#1, Y2$S$
4750 PRINT#1, T$S$
4760 PRINT#1, XADDR$
4770 PRINT#1, YADDR$
4780 PRINT#1, PADDR$
4790 PRINT#1, MXS$
4800 PRINT#1, MYS$
4810 PRINT#1, MPS$

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4760 PRINT#, NKM, NYM, NPM
4762 "COMPARISON GRAPHICS DATA FILE INFO
4764 PRINT#, GCOMP$ "FILENAME OF COMPARISON DATA SET
4766 PRINT#, $CNET$ "FLAG FOR ACTIVE GRAPHS COMPARISON
4768 "DO NOT INCLUDE MODE$" (4770 CLOSE #1
4780 RETURN
4790
4800
4810 "*** Establish communications with Personal488 ***
4820 OPEN "DEVI\ABELE\OUT" FOR OUTPUT AS #1
4830 REST Personal488
4840 EOL\OUT, "BREAK"
4850 PRINT\OUT, "RESET"
4860 "Open file to read responses from Personal488
4870 OPEN "DEV\I\E\E\E\IN" FOR INPUT AS #3
4880 "Enable SEQUENCE error detection by Personal488
4890 PRINT\3, "FILL ERROR"
4900 PRINT\3, "TIME OUT 10"
4910 RETURN
4920
4930
4950 "*** Read the signon and revision message ***
4960 PRINT\3, "HELLO"
4970 INPUT\3, AS
4980 PRINT AS
4990 RETURN
5000
5010
5050 "Put the METERS into REMOTE ***
5060 PRINT\3, "REMOTE"; XADDR$ (5070 PRINT\3, "REMOTE"; YADDR$
5080 PRINT\3, "REMOTE"; PADDR$ "K-228 Pwr Supp"
5090 RETURN
5100 "RD: Auto range X: Execute"
5110 PRINT\3, "OUTPUT"; XADDR$; ;1EHX" (5120 PRINT\3, "OUTPUT"; YADDR$; ;1FH$ (5130 PRINT\3, "OUTPUT"; PADDR$; ;1THX" (5140 PUT X-meter (K188) on #3 rear input H
5150 PRINT\3, "OUTPUT"; YADDR$; ;5FH$ "K-181: P0=0.10 OFF.TI=FRESH RUT @ TALK
5160 PRINT\3, "OUTPUT"; PADDR$ ;; COAKOG5EX" (5170 PRINT\3, "OUTPUT"; PADDR$ ;; COAKOG5EX" (5180 PRINT\3, "OUTPUT"; PADDR$ ;; COAKOG5EX" (5190 PRINT\3, "OUTPUT"; PADDR$ ;; COAKOG5EX"
5200 RETURN
5210
5230
5250 "*** PRINTOUT MESSAGE FOR BAD READING ***
5260 PRINT CHR$(7); ;IF FLGS="L" OR FLGS="I" THEN PRINT ">
5270 RETURN
5280
5290
5300 "*** ERROR TRAPPING ***
5310 PRINT CHR$(7); ;"---BEL TO INDICATE ERROR"
5320 IF ERR < 53 THEN PRINT ERR: END "---STOP AFTER ERROR"
5330 IF ERR > 53 THEN PRINT "< BAD FILENAME" (5340 FOR J = 1 TO 100: NEXT J: RESUME 240
5350 RETURN
5360
5370
5380 "*** INCREMENT EXTENSION ON DATA FILENAME ***
5390 PRINT CHR$(7)
5400 IF DNMS = "" THEN RETURN
5410 FOR J = 1 TO LEN(DNMS): IF MIDS(DNMS, J) > "." THEN NEXT J
5420 J = J + 1
5430 NEXT = VAL(LEFTS(DNMS, J)) + STR$(J) + HEXT$ (5440 HEXT$ = LEFTS(HEXT$, 3) + HEXT$
5450 PRINT
5460 RETURN
5470
5480
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5620 '  
5700 **** ANALOG OUTPUT INITIALIZATION ****  
5735 '---SLOT 3, CHANNEL 1  
5710 'CALL IONAME("ANOUT1",3,1)  'NOT USED HERE!  
5720 RETURN  
5730 '  
5740 '  
5800 **** READ IN DATA SET FOR GRAPHICS COMPARISON ****  
5865 PRINT**** RETRIEVING COMPARISON DATA SET *****  
5810 IF GCOMPL$="" THEN RETURN  
5820 OPEN#1, ",1", GCOMPL$  
5822 INPUT#, GTITLE$—TITLE OF FILE DATA  
5830 INPUT#, NDATG  
5833 INPUT#, ZG(1),XG(1),XMG(1),YG(1),QG(1)  
5840 FOR J=2 TO NDATG  
5850 INPUT#, ZG(J),XG(J),XMG(J),YG(J),QG(J)  
5855 IF ZG(J) > XM THEN XM=ZG(J): GOTO 5857  
5856 IF ZG(J) < XM THEN XMN=ZG(J)  
5857 IF XG(J) > YM THEN YM=XM(1): GOTO 5859  
5858 IF XG(J) < YM THEN YMN=XM(1)  
5860 NEXT J  
5870 CLOSE#1  
5875 PRINT" TMIN : ";XMN,"TMAX : ";XM 'Note that x-axis is "T", y-axis is X (c)  
5876 PRINT" YMIN : ";YMN,"YMAX : ";YM  
5880 RETURN  
5890 '  
5900 **** PLOT OF COMPARISON DATA ****  
5901 CLS: GOSUB 3150: GOSUB 3300 'DRAW AND LABEL AXES  
5920 FOR J=1 TO NDATG  
5930 XP=FXNXPX(ZG(J),XMN,XRNQ,DXVPX,XPNX)  
5935 IF ABS(XP) > 1000 THEN 5970 '--- PT OUT OF RANGE  
5940 YP=FYNPX(XG(J),YMN,YRNQ,DYPX,YPX)  
5945 IF ABS(YP) > 1000 THEN 5970  
5950 CIRCLE (XP,YP),1  
5960  
5990 '  
5990 '  
6000 **** REWRITE DATA TO FILE ****  
6010 IF DNMS="" THEN RETURN  
6020 OPEN#3, "F3", DNMS  
6030 PRINT**** STORING DATA ARRAY TO FILE *****  
6040 PRINT#1, "$TITLES  
6050 PRINT#1,1 '---NO. OF DATA IN SET  
6060 FOR J=1 TO  
6070 PRINT#1, ZG(J),XG(J),XMG(J),YG(J),QG(J)  
6080 NEXT J  
6090 CLOSE#3  
6100 RETURN  
6100 '  
6100 '  
6200 **** Test Temperaure for designated interval ****  
6220 IF THMNS="" THEN RETURN '--- NO THERM CALIBRATION  
6220 IF YVXPLO=0 THEN VXYPLO=1: TTMP=T: RETURN 'FIRST TIME THROUGH  
6220 DELT=T-TTMP  
6230 IF ABDDEL(T) < DELT THEN RETURN 341 'LOOP BACK FOR MORE DATA  
6250 TTMP=T: RETURN 'TO MAIN PROGRAM, STORE DATA  
6260 '  
6270 '  
6400 **** Find the average of Nv readings ****  
6410 ' ** using + & curr. read +/Sam(Vxy), +/-Sam(Vxy), +/Sam(x), Mag(Vxy), T: V(xy)  
6420 S0MVX=0: SUMY=0: SUMZ=0: SUMMM=0  
6430 PRINT#2,"output":PADXX$","ROX" 'auto-range  
6440 PRINT#2,"output":PADXX$","ROX" 'set control string  
6450 PRINT#2,"output":PADXX$","FIX" 'turn on curr  
6460 FOR J=1 TO NFILT  
6470 FOR J1=1 TO JD: NEXT J1 ' ~ .25 sec delay
6490 PRINT$, "output";XADDR$;.;RUNIX" "channel #2 for std E, sam-curr
6500 FOR J1 = 1 TO JD; NEXT J1 ' - .25 sec delay
6510 PRINT$, "ENTER";XADDR$  
6520 INPUT$, RXS$; VAL$=VAL(MIDS$1;RXS$;NXM$)
6530 IF ABS(VAL$) > 100 THEN GOSUB 550; GOTO 6480 ' - START OVER -- BAD READING
6540 PRINT$, "OUTPUT";XADDR$;.;PIX$ "K-111; PO=FILTER OFF
6550 PRINT$, "ENTER";XADDR$  
6560 INPUT$, RXS$; VAL$=VAL(MIDS$1;RXS$;NXM$)
6570 PRINT$, "output";PADDS$;SNEG$ 'v, control string for Neg Curr
6580 FOR J1 = 1 TO JD; NEXT J1 ' - .25 sec delay
6590 PRINT$, "OUTPUT";XADDR$;.;PIX$ "K-111; PO=FILTER OFF
6600 PRINT$, "ENTER";XADDR$  
6610 INPUT$, RXS$; VAL$=VAL(MIDS$1;RXS$;NXM$) 'avg + & - readings
6615 IF VAL$ > EMSTOP; GOTO 8000 'EMERGENCY Current Stop!
6620 SUMY=SUMY+VAL$; YDJD=VAL$  
6625 PRINT$, "OUTPUT";XADDR$;.;RUNIX" "channel #2 for std R, sam-curr
6630 PRINT$, "ENTER";XADDR$  
6640 INPUT$, RXS$; VAL$=VAL(MIDS$1;RXS$;NXM$)  
6650 SUMX=SUMX+VAL$  
6660 *thermometer signal reading
6666 FOR J1 = 1 TO JD; NEXT J1 ' - .25 sec delay
6670 PRINT$, "ENTER";XADDR$  
6680 INPUT$, RXS$; VAL$=VAL(MIDS$1;RXS$;NXM$)
6690 SUMZ=SUMZ+VAL$  
6710 PRINT$, "output";XADDR$;.;RUNIX" "channel #4 for Mag curr
6720 FOR J1 = 1 TO JD; NEXT J1 ' - .25 sec delay
6730 PRINT$, "ENTER";XADDR$  
6740 INPUT$, EMS$; VAL$=VAL(MIDS$1;EMS$;NXM$)
6750 SUMM=SUMM+VAL$  
6760 PRINT$, "output";PADDS$;SPOSS 'v, control string for Pos Curr
6770 NEXT J  
6772 PRINT$, "OUTPUT";XADDR$;.;RUNIX" 'channel #5: heat dissipation
6774 FOR J1 = 1 TO JD; NEXT J1 ' - .25 sec delay
6776 PRINT$, "ENTER";XADDR$  
6778 INPUT$, RMS$; HEAT=ABS(1000*X;VAL(MIDS$1;RMS$;NXM$)) 'total mW heating
6779 PRINT$, "OUTPUT";XADDR$;.;RUNIX" 'exit SUB in chann. #4
6780 PRINT$, "output";PADDS$;V.001.001W1X" 'set a very low curr
6781 IF AUTODATA=0 THEN PRINT$, "output";PADDS$;"FX" 'turn off curr
6790 SUMX=SUMX+YFILT; SUMY=SUMY+YFILT; SUMZ=SUMZ+ZFILT; SUMM=SUMM+MFFILT
6800 SUMDEV=0 'Now calc Std Dev of YD from SUMY
6810 FOR J = 1 TO NFILT
6812 SUMDEV=SUMDEV+SUM(YD(J))2
6830 NEXT J  
6840 NDEV=NFILT-1; IF NDEV=0 THEN NDEV=1
6850 QY=SQR(SUMDEV/NDEV) ' "Quality of Y" defined as Std Dev(Y)
6860 RETURN
6870 '  
6880  
7000 **MEASURE CIRCUIT RESISTANCE (HIGH CURRENT MODE)**
7002 IF MOD$="L" THEN INPUT "Remove 1 kOhm resistor and press RTN", DUM$  
7005 CLOSE ' - close any open files
7010 GOSUB 4830 ' - establish communication with Personal88
7020 GOSUB 5500 ' - put instruments in REMOTE mode & give addresses
7030 ' - for K-228: R0=wait instr command, C5=ready out,v,i
7040 PRINT$, "OUTPUT";PADDS$;"RO" 'RO=auto-range
7045 PRINT$, "OUTPUT";XADDR$;.;RUNIX" 'display heating @ contacts
7050 INPUT" What is EST RESISTANCE of circuit (ohms) ? ":,STRD
7053 RADD=1.9; IF STRD=1 THEN RADD=2
7060 INPUT" Trial CURRENT (amps) to Start with ? ",,CURI
7070 V0=CURI*STRD+RAWD*.1; V0=STRS(V0)
7075 CURI=STRS(CURI)
7080 S$="Y"+V0+"1"+CURI+"W1X"
7090 PRINT$, "OUTPUT";PADDS$;S$  
7095 PRINT$, "OUTPUT";PADDS$;"FX"
7100 FOR J = 1 TO 14000; NEXT J ' - 2.5 sec wait before read
7110 PRINT$, "ENTER";PADDS$  
170
7120 INPUT V3, VPS, CPS input power supply output voltage
7125 PRINT "INPUT", VPS, CPS, "Voltage"
7130 RCIRC = VPS/CPS
7140 PRINT "Mean circuit V, I = \( V_1 \times 10^{0.0001 \times (1000000 \times V_1 + 0.0001 \times (1000000 \times C_1 + 0.0001)) \) R = \( R \times C_1 \times V_1 \)
7150 PRINT "Do you wish to step up V 10\% per step? < Y for yes >", YESTPS
7160 IF YESTPS = "Y" THEN GOTO 7160 ELSE GOTO 7320
7170 PRINT "V(volts) I(amps) R(ohms) < ENTER to continue >"
7180 V0 = VPS: R0 = CPS
7190 V1 = 1.1*V0: C1 = 1.1*C0
7200 VPS = STR(V1): CPS = STR(R0)
7210 SPS = "\( V_1 \times 10^{0.0001 \times (1000000 \times V_1 + 0.0001 \times (1000000 \times C_1 + 0.0001)) \) R = \( R \times C_1 \times V_1 \)"
7220 SNS = "\( V_1 \times 10^{0.0001 \times (1000000 \times V_1 + 0.0001 \times (1000000 \times C_1 + 0.0001)) \) R = \( R \times C_1 \times V_1 \)"
7230 PRINT "INPUT", VPS, CPS, "Voltage"
7240 PRINT "INPUT", VPS, CPS, "Voltage"
7250 FOR J = 1 TO 1000: NEXT J
7260 PRINT "2.5sec wait before read"
7270 PRINT "CONTINUE", VPS, CPS
7280 RCIRC = VPS/CPS
7290 PRINT "Input", VPS, CPS, RCIRC, "Input", YESTPS
7300 IF YESTPS = "Y" THEN GOTO 7350 ELSE GOTO 7330
7310 GOTO 7310
7320 "Loop back for another step-up of V"
7330 IF MODE5 = "L" THEN INPUT "REINSTALL the 1 kohm resistor and press RTN", DUMS
7340 RETURN
7350
7360 " *** Find Control Parameters for Carr (K-228) ***"
7370 IF MODE5 = "L" GOTO 7580
7380 HIGH CURRENT OUTPUT RANGE
7390 VP = 1.05*XC*RCIRC
7400 "set voltage limit 5\% over min for carr & resale"
7410 CPS = STR(XC): CPS = STR(VC)
7420 VP = STR(VC): VPS = 1.05*XC
7430 SPOSS = "V = VP + I + CPS + WIX"
7440 SNEG = "V = VP + I + CPS + WIX"
7450 RETURN
7460 "LOW CURRENT OUTPUT RANGE"
7470 VP = XC*(1000 + RCIRC)
7480 "Ohms Law"
7490 IF VP > 10 THEN VP = 10
7500 "limit to 10 Vata"
7510 CLIM = 1.1*XC
7520 "set current limit 10\% over expected output"
7530 IF CLIM < .001 THEN CLIM = .001
7540 IF CLIM > .01 THEN CLIM = .01
7550 CPS = STR(VC): CPS = STR(PC)
7560 GOTO 7540
7570
7580 " ----- EMERGENCY CURRENT SHUTDOWN -----"
7590 PRINT "0" "OUTPUT", "Ainsert", "FOX" "Turn off current"
7600 BEEP: BEEP: BEEP
7610 LOCATE 25, 1: INPUT "EMERGENCY CURRENT SHUTDOWN! Press < RTN > to continue or enter < Q > to stop == >", RS
7620 IF R$ = "Q" THEN EMS$ = "Q" : RETURN 8080
7630 IF R$ = "" THEN EMS$ = "Q" : RETURN 1080
7640 PRINT "0" "OUTPUT", "Ainsert", "FIX" "resume with current"
7650 GOSUB 4090
7660 "restores message at bottom of screen"
7670 GOTO 6630
7680 RETURN 346 "to scan finished"
7690 BEEP: BEEP: BEEP
7700 LOCATE 25, 1: PRINT ""
7710 LOCATE 25, 1: INPUT "EXCESSIVE HEATING DETECTED! Enter a new heat limit (mW) or 0 to stop == >", HLIMIT
7720 IF HLIMIT < 0 THEN RETURN 346 "to scan finished"
7730 GOSUB 4090
7740 "restores message at bottom of screen"
7750 GOTO 1790
7760 ""
7770 " *** LAKESHORE TEMPERATURE CONTROLLER PARAMETERS ***"
7780 PRINT "0" "REMOTE", "TADDR$
7790 PRINT "0" "OUTPUT", "Ainsert", "PK\Fl\AFLA000"
7800 "Display Units"
7810 PRINT "0" "T > 40 THEN PRINT "0 Output", "Ainsert", "R5115D0.0W0" "Control Settings"

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Appendix C. I-V Acquisition Program

10 DEFINT LN
20 '  
30 ' *** IVT.BAS ***
40 ' *** KEITHLEY 750 SYSTEM ***
50 ' *** PERSONALABS DATA ACQUISITION ***
100 ' X-VOLTAGE (V) IS STEPPED, AS CONTROLLED BY K-228 Power Supply
105 ' Program operates digital Pwr Steep in Curve-Fit mode with 5% spare V
106 ' K-228 min step is 1/100 of any Full Range. V: 1, 10, 0.1, 0.01, 0.001, 0.0001
107 ' There is provision (Menu step 15) for manual search for ~1
110 ' ACQUIRED X1, X2 AND Y DATA UPON SPECIFIED Y-VOLTAGE CRITERION.
120 ' DATA STORED TO ASCII FILE. PLOTS AUXILIARY DATA FILE FOR COMPARISON
130 ' COMMAND TO SEND TO Y-DVM (FOR K-111 TURNS OFF DIGITAL FILTERING)
132 ' MANUAL INITIATION OF LV SETS. X1 data assumed to be Temperature
133 ' CALC Std Dev OF V-DATA FROM V-AVG. AND SAVE (unlike previous EMS dev)
134 ' WITHOUT (CURR=0) PAUSE AFTER EA READ. (no IP function)
135 ' Uses both + & - currents (like previous DA IVQY programs)
136 ' *** MINIMUM SWITCHING Version: Stays in OPERATE mode until Scan Finished
137 ' ic: Reduces care to low ON value at end of ea set of affidavit readings,
138 ' but does not go to Standby mode until end of whole scan series.
139 ' TWO RANGES: Now has a low current output mode (MODES = "L") allowing
140 ' output between 1uA and 10mA unavailable in the previous
145 ' version. This is achieved by use of a 1 kOhm Std. resister
146 ' and utilization of the voltage limit mode of the K-228.
147 '  
160 '  
200 ' *** MAIN PROGRAM ***
210 '  
220 COSUB 400 ' -- SET DEFAULT PARAMETER VALUES --
225 COSUB 4100 ' -- READ IN FILE OF SETUP AND GRAPHICS PARAMETERS --
230 COSUB 700 ' -- SIGN-ON & HARDWARE SETTINGS MENU --
235 COSUB 1000 ' -- SETUP PARAMETERS MENU --
240 COSUB 4500 ' -- STORE SETUP AND GRAPHICS PARAMS TO FILE --
250 COSUB 1600 ' -- DATA ACQUISITION INITIALIZATION --
255 FOR XC=XMIN TO XMNCX STEP DELX'--STEP SCAN X-PARAMETER
260 COSUB 7200 ' Get Pwr/Sup control params SPOSS, SNICS from XC, RCTR
265 COSUB 1750 ' -- TAKE ONE FILTERED DATUM-TEMPERURAL EMF --
270 ' COSUB 8550 ' -- CHECK FOR KEYBOARD INTERRUPT --
275 COSUB 3750 ' -- CALC. TEMP. FROM THERM. CALIBRATION --
280 IF IDAFLG=1 THEN IDAFLG=0: GOTO 310
282 ' COSUB 6200 ' -- Test TEMP. for designated interval--
290 COSUB 2100 ' -- PRINT DATA TO DISK --
300 COSUB 2700 ' -- PLOT OR PRINT DATA TO SCREEN --
310 COSUB 3250 ' -- CHECK FOR KEYBOARD INTERRUPT --
320 IF YY >= DELY GOTO 340 : PRINT " Exceeding Y-Limit" ; " End Scan - Exceed Y-lim
325 NEXT XC ' -- LOOP BACK FOR MORE DATA --
340 COSUB 7600 ' -- set K228 to "best zero" off
346 BEEP: LOCATE 24,16: PRINT"** SCAN FINISHED **",  
347 GOSUB 3550 ' -- CHECK FOR KEYBOARD INTERRUPT --  
348 GOTO 347  
349 GOTO 240  
350  
360 '*** END MAIN PROGRAM ***  
370  
390 '  
400 '*** DEFINE DEFAULT PARAMETERS ***  
410 CLS: KEY OFF: KEY 1,"LIST 200-350" + CHR(13)  
420 DEFINT I-N  
430 IF JD=30 'JD=1400 for .25sec delay after curr-switching  
432 HLIMIT = 20 'allowed safety limit for sample heating (mW)  
433 DIM X(500),Y(500),Z(500),Q(500),G(500),H(500) 'DIM DATA  
440 DIM V(500),T(500) 'ARRAY FOR THERM. CALIBRATION TABLE(e.g. DIODE V,T)  
445 DIM XQ(500),YQ(500),ZQ(500),QD(500),DQ(500) 'ARRAY OF COMPARISON DATA FOR GRAPHICS  
450 'ON ERROR GOTO 5400' -- ERROR TRAPPING  
455 R=2.5 'circuit resistance without resistor  
460 RESTORE 470  
470 DATA 10.1,1,1,1000000,0,0,1,1,1  
480 READ CUR,SCALEX,SCALEY,DELX,DELY,GO%,GI%,NFILT 'Default Params  
490 DATA "<ACTIVE>",","<ACTIVE>"  
500 READ INACT,ACTS: GSET=N: GCSET=N: GCSET=N: INACTS  
504 ' -- GPIB BUS ADDRESSES & METER PARAMS  
505 KS="KEITHLEY 181/190/197" ' -- GPIBibus ADDRESSES & METER PARAMS  
506 KPS="Keithley 221 Power Supply"  
507 DATA "X",","Y",","Z",","1",","5.5","1","L"  
508 READ XADD, YADD, PADDS, NXM, NYM, NPM, MODES  
509 MXS=KS: MYS=KS: MPS=KPS  
510 '  
520 'GRPHICS DEFAULT PARAMETERS  
530 RESTORE 550  
540 READ XMN, XMNX, YMNX, YMNX  
550 DATA 0,0,100,0,0,0,100,0,0,0,100,0  
560 READ XS, YS, XS, TS  
570 RESTORE 590  
580 READ XS, YS, XS, TS  
590 DATA "'(Amp)"","'(V)"","'(VoA)"","'(V)"","TV Curve"  
600 RESTORE 620  
610 READ EXP, DYP, XPIX, YPIX0 'AXIS CONTANTS IN PIXELS  
620 DATA 50,300,300,15  
630 RETURN 'TO MAIN PROGRAM  
640 '  
650 '  
700 '*** SIGN-ON HARDWARE SETTINGS MESSAGE ***  
710 CLS: PRINT CHR(7)  
720 PRINT:PRINT '*** HARDWARE SETTINGS ***  
730 PRINT * 1: X-INPUT: GPIB Address: "XADD": Meter ID: "MXS"  
740 PRINT * 2: Y-INPUT: GPIB Address: "YADD": Meter ID: "MYS"  
747 PRINT * 3: P-INPUT: GPIB Address: "PADDS": Por Supp ID: "MPS"  
750 PRINT:PRINT  
752 PRINT ' Meter Setup: X channel #1 < == > Thermometer Voltage Signal'  
754 PRINT ' X channel #2 < == > Sample Current Std. Resistor'  
755 PRINT ' X channel #3 < == > Sample Heat Dissipation Signal'  
756 PRINT ' Y voltmeter < == > Sample Voltage'  
758 PRINT  
760 INPUT"ENTER SELECTION # (<CR> TO CONTINUE): ".JCODE  
770 ON JCODE GOTO 790,810,840  
780 RETURN 'TO MAIN PROGRAM  
790 INPUT"ENTER NEW GPIB ADDRESS FOR X-INPUT: ",XADD  
791 GOSUB 850 ' -- METER ID CHOICES FOR READING STRIP MASKING  
792 INPUT"ENTER X-INPUT Meter ID CODE (DEFALT = PREVIOUS): ",NM  
797 IF NM < 0 THEN NM = NM ELSE 500  
798 DATA 850: MXS=MS: NXM=NXM 'ASSIGN METER ID NAME & MASKING DATA  
800 XADD=STR$(XADD): GOTO 720  
810 INPUT"ENTER NEW GPIB ADDRESS FOR Y-INPUT: ",YADD  
811 GOSUB 850 ' -- METER ID CHOICES
812 INPUT"* ENTER Y-INPUT Meter ID Code (Default = Previous): " NMT
814 IF NMT < > 0 THEN NM = NMT ELSE 320
816 OGSUB 900, MS = MS; MYM = NMSK ": ASSIGN METER ID NAME & MASKING DATA
820 YADR = STRK$YADDR; GOTO 720
840 INPUT"* ENTER NEW GPIB ADDRESS FOR P-INPUT: *, PADDR
841 OGSUB 850 = = = METE ID CHOICES
842 INPUT"* ENTER P-INPUT Meter ID Code (Default = Previous): *, NMT
843 IF NMT < > 0 THEN NM = NMT ELSE 348
844 OGSUB 900, MS = MS; NFM = NMSK ": ASSIGN METER ID NAME & MASKING DATA
848 PADDR = STRK$PADDR; GOTO 720
849 
850 "* ASSIGN STRING MASKING PARAMS FOR METER
854 PRINT "*** Meter ID Codes ***
855 PRINT " 1: KEITHLEY 181, 199, 197
856 PRINT " 2: FLUKE 840A
857 PRINT " 3: Keithley 228 Pwr Supp
860 RETURN
870 
880 
890 
900 "** ASSIGN METER ID NAME ***
910 ON NM GOTO 930, 940, 950
920 PRINT CHR$(7). PRINT ": < < < WRONG METER ID > > ": RETURN 230
930 MS = "KEITHLEY 111/199/197": NMSK = 5: RETURN
940 MS = "FLUKE 840A": NMSK = 1: RETURN
950 MS = "KEITHLEY 228 Pwr Supp": NMSK = 1: RETURN
960 
960 SCREEN 0: CLS
970 GOSUB 5500 = = = INCREMENT EXTENSION ON DATA FILENAME
980 PRINT: PRINT PRINT "*** SET-UP PARAMETERS FOR DA-IVT ***
990 IF MODES = "L" THEN PRINT " WARNING: INSTALL 1 kOhm Std. Resistor at K228 Output!!!": BEEP
1000 PRINT " 1: FILENAME OF SETUP AND GRAPHICS PARAMETERS TO USE: *.PSFLS
1010 PRINT " 2: FILENAME OF SETUP AND GRAPHICS PARAMETERS TO SAVE TO: *.PSFLS
1020 PRINT " 3: X2-VOLTAGE SCALE FACTOR (Signal/Max V or 1/5712 units): *.SCALEX
1040 PRINT " 5: Y-VOLTAGE SCALE FACTOR (Signal/Max V): *.SCALEY
1050 PRINT " 6: Y-SIGNAL LIMIT: *.DELY
1060 PRINT " 7: DATA FILENAME: *.DNMS
1070 IF DNMS = "" GOTO 1110
1080 PRINT " TITLE: *.TITLES
1090 PRINT " 8: THERM. CAL. TABLE FILENAME (for X1-signal conversion): *.TNMS
1100 IF TNMS = "" GOTO 1120
1110 PRINT " TITLE: *.TITLES
1115 PRINT " 9: TEMPERATURE INTERVAL BETWEEN DATA: *.DELT
1120 PRINT " 10: NO. OF SAMPLES IN DIGITAL FILTERING: *.RFLT
1130 PRINT " 11: SCREEN GRAPHICS PARAMETERS SETUP: *.GSET$S
1135 PRINT " 12: EXIT THE PROGRAM
1140 PRINT " 13: Test circuit resistance, or sample Ic. Present Value = *.RCIRC
1145 PRINT " 14: Ic Operating Range (0, > 1mA, L, < 1mA): *.MODES
1150 PRINT " 15: Maximum Heating Allowed (mW): *.H.LIMIT
1155 PRINT
1160 INPUT " > ENTER SELECTION # (<C/R TO EXECUTE) : *.ICODE
1165 ON ICODE GOTO 1400, 1430, 1290, 1310, 1350, 1200, 1350, 1460, 1380, 1330, 1330.1480, 1491, 1325
1170 RETURN " TO MAIN PROGRAM
1180 INPUT " ENTER Y-VOLTAGE SCALE FACTOR (Signal/Max): *.SCALEY
1190 GOTO 1200
1200 INPUT " ENTER Y-SIGNAL LIMIT: *.DELY
1210 GOTO 1200
1230 IF DNMS = "" THEN 1280
1240 PRINT: ENTER 80 CHARACTER DATA SET TITLE (Default = Previous): *.INPUT$S .DNMS
1250 IF DNUM$ = "" THEN 1270
1260 TITLES = DNMS
1270 FOR J = 1 TO LEN(DNMS): IF MID$(DNMS, J, 1) < > "> " THEN NEXT J ELSE 1280
1272 DNMS = DNMS + ".D78"
1280 GOTO 1200
1290 INPUT " ENTER X-VOLTAGE SCALE FACTOR (Signal/Max): *.SCALEX

174
1300 GOTO 1020
1310 INPUT * ENTER X-SIGNAL RANGE & STEP SIZE(XMIN,XMAX,STEP(ABs Amps)); *.XMIN,XMAX,DELX
1315 * INPUT * ENTER X-SIGNAL BACKSTEP (FRACTION OF CURRENT V): *.XOFFPC
1320 GOTO 1020
1325 INPUT * ENTER MAXIMUM HEATING ALLOWED (mW): *.HRELIM
1326 GOTO 1020
1330 GOSUB 2250 * Define Graphics Parameters
1332 GOTO 1020
1333 GOSUB 4500; END  * STORE PARAMS TO FILE AND EXIT
1340 GOTO 1020
1350 INPUT * ENTER THERMOM. CALIB. FILENAME (EXT.CAL WILL BE ADDED): *.THINMS
1350 IF THINMS = "*" THEN 1370 ELSE THINMS = THINMS + ".CAL.*
1360 GOSUB 1900  * READ IN THERM. CALIB. DATA ---
1365 INPUT * ENTER VOLTAGE SCALE FACTOR (signal/voltage): *.SCALEZ
1370 GOTO 1020
1380 INPUT * ENTER NO. SAMPLES IN DIGITAL FILTERING: *.NFILT
1390 GOTO 1020
1400 INPUT * ENTER FILENAME FOR SETUP PARAMS. TO USE (.EXT.PAR WILL BE ADDED): *.PFLS
1410 IF PFLS = "*" THEN 1420 ELSE PFLS = PFLS + ".PAR.*
1420 GOSUB 4510; GOTO 230  * READ IN SETUP AND GRAPHICS PARAMS
1430 INPUT * ENTER FILENAME FOR SETUP PARAMETERS TO SAVE TO (.PAR WILL BE ADDED): *.PSFLS
1440 IF PSFLS = "*" THEN 1450 ELSE PSFLS = PSFLS + ".PAR.*
1450 GOTO 1020
1460 INPUT * ENTER TEMPERATURE INTERVAL BETWEEN DATA: *.DELT
1470 GOTO 1020
1480 GOSUB 7000  * Check out circuit resistance
1490 GOTO 1020
1500 INPUT * ENTER OPERATING RANGE (H. > 1mA; L. < 10mA): *.MDES
1510 IF MDES = "H" THEN GOSUB 1800; GOTO 1020
1510 IF MDES = "L" THEN GOSUB 1810; GOTO 1020
1514 PRINT "Error": BEEP: GOTO 1491
1514 "
1515 "
1516 *** OPEN DATA FILE ***
1517 IF DNMS = "*" THEN 1550
1520 OPEN "J", #1, DNMS
1530 PRINT #1, TITLES
1540 PRINT #1, "I(A) uVolts T(K) Std Dev(V) Heating(mW)"
1550 RETURN
1560 "
1570 "*** INITIALIZATION FOR DATA ACQU. ***
1580 CLOSE  *--- Close any open files
1590 GOSUB 4050; *PRINT MESSAGE AT SCREEN BOTTOM
1600 I=0 * INITIALIZE DATA ARRAY INDEX
1610 XOFFE = 2047  * COUNTS FOR ZERO CURRENT THERMAL
1610 GOSUB 4850  * ESTABLISH COMMUNICATION W/PERSONA.88
1610 GOSUB 4950  * SENSOR MESSAGE
1610 GOSUB 5050  * ASSIGN REMOTE MODE ADDRESSES
1614 "GOSUB 5700  * INITIALIZE FOR ANALOG OUTPUT xx not used here
1614 FILE5 = 1  * INITIALIZE FOR DATA SCREEN PRINTOUT
1614 GOSUB 1500  * OPEN DATA FILE
1617 PRINT@2, "output",#ADDR5; ";N2X * Channel L2 for Isawa std-R
1610 IFXVLO = 0 *--- FLAG FOR FIRST TIME THRU
1700 PRINT *** Beginning Data Acquisition ***
1700 PRINT * # I(A) V Std Dev(V) T(K) Heating(mW)"
1710 RETURN TO MAIN PROGRAM
1720
1730 * *** TAKE DATA SAMPLE ***
1740 * --- GPB INPUT ---
1770 GOSUB 6400  * FIND AVG OF NFILT GPB REA DINGS
1780 VX = ABS(SUM*XSCALE); VY = ABS(SUM*YSCALE); VZ = ABS(SUM*ZSCALE)
1790 IF HEAT > HRELIM GOTO 8100  * Excessive heating detected
1790 RETURN TO MAIN PROGRAM
1800 SOUN D 880, 15
1802 INPUT * REMOVE 1 kOhm std. Resistor then press RTN".DUMS
1805 RETURN
1810 SOUND 880, 15
1815 INPUT "INSTALL 1 kOhm Sld. Resistor then press RTN",DUM$
1820 RETURN
1830
1840 '
2000 ' **** PRINT VALUES ON DISK ****
2020 1=1:1;X0=;Y0=;Q0=;QY=;H0=;HAT 'INCREMENT INDEX
2030 IF THMNS="" THEN ZH=;V2;GOTO 2040
2040 ZH=T
2060 RETURN 'TO MAIN PROGRAM
2070 '
2080 '
2100 ' **** TEST TO REDRAW GRAPHICS *****
2110 IF VST> =5 THEN G% =1:GOTO 2150
2120 IF VST> =2 THEN G% =2:GOTO 2150
2130 IF VST> =1 THEN G% =3:GOTO 2150
2140 G% =10
2150 RETURN
2160 IF VST> =7 THEN G% =G%:GOSUB 1790:RETURN 'CHANGE TO NEW X-GAIN
2170 G% =G%:GOSUB 1790 'CHANGE TO NEW Y-GAIN
2180 RETURN
2190 '
2200 '
2220 ' **** GRAPHICS PARAMETERS ****
2250 CSHTR=$=ACTS'SCREEN GRAPHICS ACTIVE
2270 PRINT: PRINT: PRINT: *** SCREEN GRAPHICS PARAMETERS ***
2280 PRINT: 1: I-axis Inad, Inax = ;XMIN,XMAX
2290 PRINT: 2: V-axis Vmin, Vmax = ;YMIN, YMAX
2300 PRINT: 4: V-axis label = ;XS
2310 PRINT: 5: Graph Title = ;TS
2320 PRINT: 6: COMPARISON DATA SET FILENAME = ;GCOMPL5
2350 PRINT: TTTLE: ;GTTLS
2367 PRINT: 7: VIEW COMPARISON DATA SET: ;GCST5
2370 PRINT
2380 ' ENTER SELECTION # (<CR> TO MAIN MENU): ;,ICDE
2390 ON ICODE GOTO 2370,2390,2340,2430,2470,2481,2493
2390 GOTO 2490
2400 INPUT* ENTER I-axis Inon = ;XMIN, XMAX
2410 GOTO 2270
2420 GOTO 2270
2430 INPUT* ENTER V-axis Vmin, Vmax = ;YMIN, YMAX
2440 GOTO 2270
2450 INPUT* ENTER I-axis label = ;X5
2460 GOTO 2270
2470 INPUT* ENTER Graph Title = ;TS
2480 GOTO 2270
2490 INPUT* ENTER DATA SET FILENAME = ;GCOMPL5
2505 GOSUB 5900: GOTO 2270 'READ IN DATA SET FROM FILE
2515 INPUT* 'VIEW PLOT OF DATA SET ;YES?); "ANSS
2525 IF ANSS="Y" OR ANSS="Y" THEN GCSETS=ACTS ELSE GCSETS=INACTS:GOTO 2270
2535 GOSUB 2490 'DEFINE GRAPH AXES RANGES
2545 GOSUB 5900 'PLOT DATA SET
2555 GOSUB 4111 'PRINT MESSAGE AT SCREEN BOTTOM
2565 IF INKEYS="" THEN 2488 ELSE SCREEN 0: GOTO 2270
2575 '
2580 YRNG=MAX;YMIN: YRNG=MIN;YMEN
2590 XMIN=STR$(XMIN): XMAX=STR$(XMAX)
2605 YMIN=STR$(YMIN): YMAX=STR$(YMAX)
2610 GOSUB 2610: GOSUB 2660 'DEFINE FUNCTION TO CALC COORD IN PIXELS
2620 RETURN
2540 '  
2550 '  
2610 DEF FNPIX(X,Y,XMIN,YMIN,YRNG,DXPIX,YPIX) = (YVAR-YMIN)*DXPIX/YRNG + YPIX + DXPIX  
2620 RETURN  
2630 '  
2640 '  
2660 DEF FNPIX2(XVAR,XMIN,XRNG,DXPIX,YPIX) = (XVAR-XMIN)*DXPIX/XRNG + XPIX  
2670 RETURN  
2680 '  
2690 '  
2700 ' *** PLOT OR PRINT DATA ***  
2710 IF INKS < > "L" THEN IF INKS < > "F" THEN 2740  
2720 IF FLGS = "L" THEN 2780  
2730 FLCS = "L", GOSUB 3050: GOSUB 4050: RETURN 'LIST DATA TO CURRENT I  
2740 IF CSHT = INACTS THEN 2780  
2750 IF INKS < > "F" THEN IF INKS < > "P" THEN 2780  
2760 IF FLCS = "P" THEN 2800  
2770 FLCS = "P", GOSUB 2900: GOSUB 4050: RETURN 'PLOT DATA TO CURRENT I  
2780 IF FLCS < > "L" THEN GOTO 2790  
2790 PRINT USING " ***: I;  
2800 PRINT USING " +###.####### +X0,0;  
2810 PRINT USING " +###.####### +Y0,0;  
2820 PRINT USING " +###.####### Z0,0,0,0;  
2830 RETURN 'TO MAIN PROGRAM  
2840 IF CSHT = INACTS THEN 2860  
2850 XP = FNPIX(X0,XMIN,XRNG,DXPIX,YPIX)  
2860 IF XP > 10000 THEN 2840  
2870 YP = FNPIX(Y0,YMIN,YRNG,DXPIX,YPIX)  
2880 IF YP > 10000 THEN 2840  
2890 PLOT (XP,YP) 'PLOTS POINT  
2900 IF THNMS = " " GOTO 2840  
2910 LOCATE 1,6: PRINT"T=""" \INT(D) \times K";  
2920 LOCATE 2A,1  
2930 RETURN 'TO MAIN PROGRAM  
2950 '  
2960 ' *** REFRESH PLOT OF DATA UP TO CURRENT POINT ***  
2970 CLS: GOSUB 3150: GOSUB 3300 'DRAW AND LABEL AXES  
2980 FOR J = 1 TO 1  
2990 XP = FNPIX(X(J),XMIN,XRNG,DXPIX,YPIX)  
3000 IF ABS(XP) > 10000 THEN 2970 '---PT OUT OF RANGE  
3010 YP = FNPIX(Y(J),YMIN,YRNG,DXPIX,YPIX)  
3020 IF ABS(YP) > 10000 THEN 2970  
3030 'CIRCLE (XP,YP),3  
3040 'NET (XP,YP)  
3050 NEXT J  
3060 IF GOMELS = " " THEN RETURN  
3070 IF CSHT = ACTS THEN GOSUB 5920 'PLOT COMPARISON DATA  
3080 RETURN  
3090 '  
3100 '  
3120 '  
3130 '  
3140 ' *** SUBTO DRAW GRAPHS AXES ***  
3150 ***

177
3169 SCREEN 9 'HI RES GRAPHICS SCREEN
3170 CLS
3180 PRINT (46,15)
3190 DWN=300; ROT=550; TCKX=30; TCKR=55; ZERO=0
3200 FOR J=1 TO 10: DRAW"D"=TCKX,NM+550,0; "NEXT J 'LEFT AXIS
3210 FOR J=1 TO 10: DRAW"R"=TCKR,NM+6,300; "NEXT J 'BOTTOM HORIZ AXIS
3220 DRAW"U"=DWN;L=ROT;
3230 RETURN
3240
3250
3300 *** SUB TO LABEL AXES ***
3310 IF LENS(X)>60 THEN X5=LENS(X$)$ TRUNCATE IF TOO LONG
3320 XAX=44,5*LENS(X$)
3330 LOCATE 24,XAX; PRINT X$;
3340 IF LEN(Y$)>7 THEN Y1S=LEFT(Y$),9 'TRUNCATE IF TOO LONG
3350 TAX=5.5*LEN(Y$)
3360 LOCATE 12,TAX; PRINT Y1S;
3370 IF LEN(Y$)>7 THEN Y2S=LEFT(Y$),9
3380 TAX=5.5*LEN(Y$)
3390 LOCATE 13,TAX; PRINT Y2S;
3400 IF LENS(T$)>70 THEN T5=LENS(T$),70 'TRUNCATE IF TOO LONG
3410 TAX=44,5*LENS(T$)
3420 LOCATE 1,TAX; PRINT T$;
3430 LOCATE 24,12-LEN(XMIN$); PRINT XMIN$;
3440 IF XMAXS=" " THEN 3460
3450 LOCATE 24,81-LEN(XMAXS$); PRINT XMAXS$;
3460 LOCATE 23,10-LEN(YMIN$); PRINT YMIN$;
3470 LOCATE 21,10-LEN(YMAXS$); PRINT YMAXS$;
3480 RETURN
3490
3500
3550 *** SUB TO CHECK KEYBOARD STATUS ***
3560 IN$=INKEY$;
3570 IF IN$=" " THEN RETURN
3575 IF IN$="CHR$(13) THEN 255 'INITIATE ANOTHER SET OF READINGS
3580 IF IN$="CHR$(13) THEN MATELO=1: GOTO 3710 'MANUAL DATA STORAGE
3590 INK$=IN$;
3600 IF INK$="q" AND INKS$="q" THEN 3610
3610 IF INMS$=" " THEN 3630 'DATA FILENAME
3620 CLOSE #1: GOSUB 6600 'REWRITE DATA TO FILE IN STD FORMAT
3630 SCRN$(0): INPUT "ANOTHER DATA SET (y)?:";ANS$25
3640 IF ANS$25="y" OR ANS$25="n" THEN 3670
3650 ON ERROR GOTO 0 'DISABLE ERROR TRAPPING
3660 CLS: END
3670 CLOSE: RETURN 240 'TO MAIN PROGRAM AT MENU
3680 IF INK$="p" THEN INK$="p" THEN RETURN
3690 IF INK$="l" THEN INK$="l" THEN RETURN
3700 RETURN 350 'TO MAIN PROGRAM AT PLT OR PRINT DATA
3710 RETURN 360 'TO MAIN PROGRAM AT TAKE ONE DATUM
3720
3730
3730 *** SUB TO INTERPOLATE TEMPERATURES FROM DIODE T_V TABLE ***
3760 IF THNMS=" " THEN RETURN 'TO MAIN PROGRAM
3770 VZC=VZ
3780 NLO=1: NH=NDATA 'LOW AND HI INDICES OF TABLE DATA
3790 N=(NHI+NLO)/2 'INTEGER DIVIDE TABLE INDEX TO BE COMPARED TO DATUM
3800 IF VZC<V(NH) THEN NH=N: GOTO 3820
3810 NLO=N
3820 IF NH<0 THEN COTO 3790
3830 T=(NHI)+(VZC-V(NHI))*CONVBD/(T(NH)-V(NHI)-V(NLO))
3840 RETURN
3850
3860
3890 *** SUB TO READ IN THRM. CALIB DATA ***
3910 IF THNMS=" " THEN RETURN
3920 THNMS$=THNMS
3930 PRINT*** Reading therm. calibration table ***
3940
3910 OPEN "I", #1, 'THNMS
3912 INPUT #1, THTLS ' - TITLE OF DATA SET
3960 INPUT #1, NDATA
3970 FOR J = 1 TO NDATA
3980 INPUT #1, Y(J), TO(J)
3990 NEXT J
4000 CLOSE #1
4010 RETURN
4020 ' 
4030 ' 
4040 ' **** PRINT MESSAGE AT BOTTOM OF SCREEN ****
4050 IF OSET$ = " ACTS THEN 4090
4060 CLR: LOCATE 25, 1: PRINT "PRESS<CR> STORE PT. <Q> QUIT";
4070 LOCATE 1, 1: OGOY 4110
4090 LOCATE 25, 1: PRINT "PRESS<CR> STORE PT. <Q> QUIT <P> PLOT RESTORE <1.> LIST";
4110 LOCATE 24, 1
4110 RETURN
4111 LOCATE 25, 1: PRINT "PRESS<CR> TO CONTINUE";
4112 LOCATE 24, 1
4113 RETURN
4120 ' 
4130 ' 
4150 ' **** READ IN SETUP AND GRAPHICS PARAMETERS ****
4160 IF OSET$ = " ACTS THEN RETURN
4170 OPEN "I", #1, PUTF$5
4180 PRINT "**** RETRIEVING PARAMETERS FROM " PUTF$; " ****
4190 ' --SETUP PARAMETERS
4195 INPUT #1, PUTF$5
4200 INPUT #1, SCALEx
4205 INPUT #1, RCRC
4207 INPUT #1, XMIN, XMAX, XMNC, XMNX, DELX
4210 INPUT #1, XOFFC
4220 INPUT #1, SCALey
4230 INPUT #1, DELY
4240 INPUT #1, DNMS
4250 INPUT #1, TITLe5
4260 DUM$=TITLe5
4270 INPUT #1, THNMS
4272 INPUT #1, SCALIZ
4275 INPUT #1, DELT
4280 INPUT #1, INFILT
4290 INPUT #1, GSET$5
4300 ' --GRAPHICS PARAMETERS
4310 INPUT #1, XMIN, XMAX
4320 INPUT #1, YMIN, YMAX
4330 INPUT #1, X5
4340 INPUT #1, Y5
4350 INPUT #1, Y25
4360 INPUT #1, IT5
4370 ' --COLOR & METER PARAMS
4380 INPUT#1, XADD$5
4390 INPUT#1, YADD$5
4397 INPUT#1, PADD$5
4400 INPUT#1, MX5
4410 INPUT#1, MY5
4417 INPUT#1, MPS
4420 INPUT#1, NXM, NYM, NPM
4422 ' --COMPARISON GRAPHICS DATA FILE INFO
4424 INPUT#1, GCOMPS$5 'DATA FILENAME
4426 INPUT#1, GOSETS$5 'FLAG FOR GRAPHICS COMPARISON
4430 CLOSE #1
4435 GOSUB 3490 ' --READ IN THERM CALIB. DATA
4440 IF GSET$ = "ACTS THEN GOSUB 3800: GOSUB 2490 ' --READ IN COMB DATA SET
4450 RETURN
4460 ' 
4470 ' 
4500 ' **** SAVE SETUP AND GRAPHICS PARAMETERS TO FILE ****
4510 IF PSPLS$ = "" THEN RETURN
4520 OPEN "O", #1, PSPLS$
4530 PRINT*** STORING PARAMETERS TO: "PSPLS; ***"
4540 ---SETUP PARAMETERS
4550 PRINT#, PSPLS$
4560 PRINT#, SCALEX
4570 PRINT#, SCALEY
4580 PRINT#, DELT
4600 PRINT#, TITLES
4610 PRINT#, TITLES
4612 PRINT#, SCALEZ
4615 PRINT#, DELT
4620 PRINT#, NFILT
4630 PRINT#, GSET$
4640 ---GRAPHICS PARAMETERS
4650 PRINT#, XMIN, XMAX
4660 PRINT#, YMIN, YMAX
4670 PRINT#, XS
4680 PRINT#, YS
4690 PRINT#, YS
4700 PRINT#, T$
4710 ---PLOT & METER PARAMS
4720 PRINT#, XADDR$, YADDR$
4730 PRINT#, PADDR$
4737 PRINT#, ADDR$
4740 PRINT#, MX$
4750 PRINT#, MY$
4757 PRINT#, NPM$
4760 PRINT#, XNM, YNM, NPM
4762 ---COMPARISON GRAPHICS DATA FILE INFO
4764 PRINT#, CCOMPLS$ 'FILENAME OF COMPARISON DATA SET
4766 PRINT#, CCSETS 'FLAG FOR ACTIVE GRAPHICS COMPARISON
4770 CLOSE#1
4780 RETURN
4790 '
4830 *** Establish communications with PersonalH88 ***
4840 OPEN "D:\DEV\EEXECUT" FOR OUTPUT AS #2
4870 'Reset PersonalH88
4890 IOCTL#2, "BREAK"
4895 PRINT#, "RESET"
4890 'Open file to get responses from PersonalH88
4900 OPEN "D:\DEV\EEXEC" FOR INPUT AS #3
4904 'Enable SEQUENCE error detection by PersonalH88
4905 PRINT#, "FILL ERROR"
4906 PRINT#, "TIME OUT 10"
4910 RETURN
4920 '
4930 '
4950 *** Read the sigma and revision message ***
4960 PRINT#, "HELLO"
4970 INPUT#, AS$
4980 PRINT AS$
4990 RETURN
5000 '
5010 '
5050 *** Put the METERS into REMOTE ***
5060 PRINT#, "REMOTE", YADDR$
5070 PRINT#, "REMOTE", XADDR$
5075 PRINT#, "REMOTE", FADERS "K-228 Par Supp"
5080 RETURN
5089 'R0 Auto range X: Execute
5100 PRINT#, "OUTPUT", XADDR$, "$\text{ROM\#X}$"
5110 PRINT", "'OUTPUT', YADD$(1); 'POT1X' 'K-141': PU=FILTER OFF, T1=FRESH BUF @ TALK
5117 PRINT", "'OUTPUT', YADD$(1); 'C0AgROG5X' 'K0'—wait finish. G5=v,i val read
5120 RETURN
5120 '}
5120 '}
5120 '}
5120 '}
5120 '}
5350 '**** PRINT/OUT MESSAGE FOR BAD READING ****
5360 PRINT CHR$(13); IF FLO$="1." OR FLO$="1" THEN PRINT ""; > BAD READING<< << "",$R
5370 RETURN
5380 '}
5380 '}
5380 '}
5390 '}
5390 '}
5400 '**** ERROR TRAPPING ****
5410 PRINT CHR$(13); '—BELL TO INDICATE ERROR
5415 IF ERR < > 53 THEN PRINT ERR; END '——STOP AFTER ERROR
5420 'IF ERR < > 53 THEN RESUME 260 '——TRY TO TAKE MORE DATA
5425 PRINT""; > BAD FILENAME<< << "": FOR J=1 TO 1000: NEXT J: RESUME 240
5440 '}
5440 '}
5440 '}
5440 '}
5440 '}
5500 '*** INCREMENT EXTENSION ON DATA FILENAME ***
5510 PRINT CHR$(7)
5520 IF DNMS="" THEN RETURN
5530 FOR J=1 TO LEN(DNMS): IF MID$(DNMS, J, 1)="">" THEN NEXT J
5540 J=LEN(DNMS)+1
5550 EXTS=RIGHT$(DNMS, J): DNMS=LEFT$(DNMS, J-1)
5560 EXTS=VALUE(RIGHT$(EXT$(3)), i): TEXT=TEXT+i
5570 EXTS=RIGHT$(STR$(EXT$(3)), i)
5580 EXTS=LEFT$(EXT$(3-3), EXTS)
5590 DNMS=DNMS+EXTS
5600 RETURN
5610 '}
5610 '}
5610 '}
5610 '}
5610 '}
5700 '**** ANALOG OUTPUT INITIALIZATION ***
5710 '—SLOT 3, CHANNEL 1
5720 'CALL IONAME('ANOUT1', 3,1)
5730 RETURN
5740 '
5750 '}
5760 '}
5770 '}
5780 '}{*
5790 '**** READ IN DATA SET FOR GRAPHICS COMPARISON ***
5800 PRINT"**** RETRIEVAL COMPARISON DATA SET *****
5810 IF GCOMP=="" THEN RETURN
5820 OPEN",", #1", GCOMP, 15
5830 INPUT#, 1, GET$(7) '—TITLE OF FILE DATA
5840 INPUT#, XG(I), YG(I), ZG(I), QG(I), DUMMY
5850 XMX=XG(I): XMN=XG(I): YMX=YG(I): YMN=YG(I)
5860 FOR J=2 TO NDATA
5870 INPUT#, XG(I), YG(I), ZG(I), QG(I), DUMMY
5880 IF XG(I)>XMX THEN XMN=XG(I): GOTO 5857
5890 IF YG(I)>YMX THEN YMN=YG(I): GOTO 5857
5900 IF YG(I)<YMN THEN YMN=YG(I)
5910 NEXT J
5920 CLOSE #1
5930 PRINT"XMIN: "': XMN, "XMAX: "': XMX
5940 PRINT"YMIN: "': YMN, "YMAX: "': YMX
5950 RETURN
5960 '}
5970 '}
5980 '}
5990 '}
5990 '}
6000 CLS: GOSUB 3150: GOSUB 3300 'DRAW AND LABEL AXES
6010 FOR J=1 TO NDATA
6020 IF J=0 THEN S=0
6030 XP=FXNXPX(XG(I), XMN, XRG, DXPIX, XPX)
6040 YP=FYNYPX(YG(I), YMN, YRG, DYPIX, YPX)
6050 IF AB | XP>10000 THEN 5970 '— IF OUT OF RANGE
6060 5970 IF AB | YP>10000 THEN 5970
6070 CIRCLE (XP, YP), 1
6080 'PSET (XP, YP)
5970 NEXT J
5980 RETURN
5990 *
6000 "*** REWRITE DATA TO FILE ***"
6010 IF DNMS="" THEN RETURN
6020 OPEN"O",#1, DNMS
6030 PRINT"*** STORING DATA ARRAY TO FILE ***"
6040 PRINT#1, TITLES$  
6050 PRINT#1,1 "-NO OF DATA IN SET
6060 FOR J = 1 TO 1
6070 PRINT#1, X(J);Y(J);Z(J);Q(J);H(J)
6080 NEXT J
6090 CLOSE#1
6100 RETURN
6110 *
6200 "Test Temperature for designated interval ***
6210 IF THMNS="" THEN RETURN "NO THERM CALIBRATION"
6220 IF IVXFLO=0 THEN IVXFLO=1; TTMP=T: RETURN "FIRST TIME THROUGH"
6230 DELAY "T-TTMP"
6240 IF ABS(DELAY)<=DELT THEN RETURN 340 "LOOP BACK FOR MORE DATA"
6250 TTMP=T: RETURN "TO MAIN PROGRAM, STORE DATA"
6260 '
6270 '
6400 "*** Find the average of Navg readings ***"
6410 SUMN=0; SUMY=0; SUMZ=0
6420 PRINT#0, "nout":PADDR$:"RX" "auto-range"
6430 PRINT#0, "nout":PADDR$:"SP0S" 'v.i control string
6450 PRINT#0, "nout":PADDR$:"FIX" 'turn on + curr
6455 FOR J = 1 TO NFILT
6460 FOR J = 1 TO JD: NEXT J ' - .25 sec delay for JD=1400
6465 PRINT#0, "nout":XADDR$:"XN2X" 'X channel #2
6470 PRINT#0, "nout":XADDR$:"XN2X" 'X channel #2
6480 INPUT#3, RX$: VALX=VAL(MIDS(RX5,NX5))
6490 IF ABS(XVAL) > 100 THEN GOSUB 350: GOTO 6410 "START OVER -- BAD READING"
6500 PRINT#0, "nout":XADDR$:"P0X" 'X-181: P0=FILTER OFF
6510 PRINT#0, "nout":XADDR$:"XN2X"
6520 INPUT#3, RX$: VALX=VAL(MIDS(RX5,NX5))
6530 PRINT#0, "nout":PADDR$:"W-.001-.001WIX" 'v.i control string for NEG curr
6540 PRINT#0, "nout":PADDR$:"SP0S" 'v.i control string for POS curr
6550 FOR J = 1 TO JD: NEXT J ' - .25 sec delay for JD=1400
6560 PRINT#0, "nout":XADDR$:"XN2X" 'X channel #1
6570 PRINT#0, "nout":XADDR$:"XN2X"
6580 "single read of temperature signal while Sample Curr ON"
6590 PRINT#0, "nout":XADDR$:"XN2X" 'X channel #1
6580 SUMX=SUMX+VALX
6590 FOR J = 1 TO JD: NEXT J ' - .25 sec delay
6600 PRINT#0, "nout":XADDR$:"XN2X" 'channel #3: heat dissipation
6610 FOR J = 1 TO JD: NEXT J ' - .25 sec delay
6620 PRINT#0, "nout":XADDR$:"XN2X"
6630 "channel #3: heat dissipation
6640 PRINT#0, "nout":XADDR$:"XN2X"
6650 IF RMS:"HEAT"=ABS(1000*X)VAL(MIDS(RM8,NX8))=total mW heating
6660 PRINT#0, "nout":XADDR$:"XN2X" 'exit SUB in channel #1
6670 S0S="W-.001-.001WIX"
6680 PRINT#0, "nout":PADDR$:"W-.001-.001WIX" 'v.i control string for POS curr
6690 PRINT#0, "nout":XADDR$:"SP0S" 'v.i control string for POS curr
6700 SUMX=SUMX+VALX
6710 NEXT J
6720 FOR J = 1 TO NFILT
6730 SUMDEV=SUMDEV+(SUMY-YD)
**MEASURE CIRCUIT RESISTANCE (HIGH CURRENT MODE)**

**1.** IF MODE$ = "1," THEN PRINT$ "REMOVE 1 kΩ resistor then press RTN", DUM$.
**2.** CLOSE C:
**3.** GO SUB 4820 — establish communication with Personal488
**4.** GO SUB 5050 — put instruments in REMOTE mode & give addresses
**5.** "for K=225: K=wait instrn complete. CS=ready" V,i
**6.** PRINT$, "OUTPUT", "RAXX", "R5X = auto-range
**7.** PRINT$, "OUTPUT", "ADDXX", "RUNXX" "display connect heating
**8.** INPUT$, "What is EST RESISTANCE of circuit (ohms)?", STDR
**9.** RADD = 1.9: IF STDR = 1 THEN RADD = .2
**10.** INPUT$, "Trial CURRENT (amps) to start with?", CUR
**11.** VO = CUR$*(STDR+RADD*1.2): V0$ = STR$(V0)
**12.** CUR$ = STR$(CUR)$
**13.** SS$ = "V$ = V0$+1" + CUR$ + "WIX"
**14.** PRINT$, "OUTPUT", "PADD\$", S$S
**15.** PRINT$, "OUTPUT", "PADD\$, V0$"
**16.** FOR J = 1 TO 14000: NEXT J — 2.5 sec wait before read
**17.** PRINT$, "ENTER", "PADD\$"
**18.** INPUT$, "VPS, CPS", CVS, read pwr supp output vi
**19.** DOC LBL$, "BREAK"
**20.** PRINT$, "OUTPUT", "PADD\$, V0$"
**21.** RCIRC = VPS/CPS
**22.** PRINT$, "Meas$ circuit V, I = " + VPS, CPS: ; PRINT$ = => R = + RTRC
**23.** INPUT$ Do you wish to step up V 10% per step? < Y for yes > ; YES$PS
**24.** IF YES$PS = "Y" THEN GOTO 7170 ELSE GOTO 7330
**25.** PRINT$ V(volts) (amps) R(ohms) < ENTER to continue >
**26.** VO$ = VPS: CVS = CPS
**27.** VI$ = 1.1*VO: C1 = 1.2*C0
**28.** VI$ = STR$(VI$): CI$ = STR$(C1$)
**29.** SS$ = "V$ = VI$+1" + CI$ + "WIX"
**30.** SNS$ = "V$ = VI$+1" + CI$ + "WIX" "reg not used here
**31.** PRINT$, "OUTPUT", "PADD\$, S$S
**32.** PRINT$, "OUTPUT", "PADD\$, S$S
**33.** FOR J = 1 TO 14000: NEXT J — 2.5 sec wait before read
**34.** PRINT$, "ENTER", "PADD\$"
**35.** INPUT$, "VPS, CPS", CVS, read pwr supp output vi
**36.** DOC LBL$, "BREAK"
**37.** PRINT$, "OUTPUT", "PADD\$, V0$"
**38.** RCIRC = VPS/CPS
**39.** PRINT$, VPS, CPS, RCIRC$: ; INPUT$ "YESTPS
**40.** IF YES$PS = "Y" THEN GOTO 7320 ELSE GOTO 7330
**41.** GOTO 7180 "Loop back for another step-up of V
**42.** IF MODE$ = "L" THEN INPUT "REINSTALL the 1 kΩ resistor then press RTN", DUM$
**43.** RETURN

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**Final Control Params for Curve (K-225)**

**1.** IF MODE$ = "L", GOTO 7580
**2.** HIGH Current Output Range ...
**3.** VF = 1.05*XC*RCIRC "set voltage limit 5% over min for curr & resi
**4.** CPS = STR$(XC): CPNS = STR$(XC)
**5.** VPS = STR$(VF): VPS = STR$(VF)
**6.** SPOS$ = "V$ = VPS + "T" + CPS + "WIX"
**7.** SPOS$ = "V$ = VPS + "T" + CPNS + "WIX"
**8.** RETURN

**LOW Current Output Range ...
**9.** VF = VC*(1000 + RCIRC) "Ohm's Law
**10.** IF VF = 10 THEN VF = 10 "Limit to 10 Volts
**11.** CLIM = 1.1*VC "Set current limit 10% over expected output
Appendix D. X-Y Plotter Emulator

10 DEFINT I-N
20 ' 30' *** DRIFT BAS ***
40 ' *KEITHLEY 570 SYSTEM ***
50 ' * Y-VOLTAGE VS X-VOLTAGE -- PERSONAL488 DATA ACQUISITION ***
100 ' DATA SAMPLED AFTER SPECIFIED X- & Y-ABS-VALUES-INTERVALS HAVE PASSED
110 ' OUTPUTS X AND Y DATA TO AN ASCII FILE
120 ' SPECIFIED BY THE USER. PLOTS AUXILIARY DATA FILE FOR COMPARISON
130 ' COMMAND TO SEND TO Y-DVM (FOR X-181 TURNS OFF DIGITAL FILTERING)
140 ' 200 ' *** MAIN PROGRAM ***
210 ' 220 GOSUB 400 'SET DEFAULT PARAMETER VALUES ---
225 GOSUB 4150 'READ IN FILE OF SETUP AND GRAPHICS PARAMETERS ---
230 GOSUB 700 'SIGN-ON & HARDWARE SETTINGS MENU ---
240 GOSUB 1000 'SETUP PARAMETERS MENU ---
245 GOSUB 4500 'STORE SETUP AND GRAPHICS PARAMS TO FILE ---
250 GOSUB 1600 'DATA ACQUISITION INITIALIZATION ---
260 GOSUB 1750 'TAKE ONE DATUM SAMPLE ---
270 GOSUB 3550 'CHECK FOR KEYBOARD INTERRUPT ---
280 GOSUB 1850 'TEST DATA FOR OUTPUT ---
290 GOSUB 3550 'CHECK FOR KEYBOARD INTERRUPT ---
300 GOSUB 3750 'CALC. TEMP. FROM THERM. CALIBRATION ---
310 GOSUB 3000 'PRINT DATA TO DISK ---
320 GOSUB 2700 'PLOT OR PRINT DATA TO SCREEN ---
330 GOSUB 3550 'CHECK FOR KEYBOARD INTERRUPT ---
340 GOTO 260 'LOOP BACK FOR MORE DATA ---
350 ' 360 '*** END MAIN PROGRAM ***
370 ' 380 ' 400 ' *** DEFINE DEFAULT PARAMETERS ***
410 CLS: KEY OFF: KEY 1,"LIST 200-400" +CHR$(13)
420 DEFINT I-N
430 DIM X(1000),Y(1000) 'DIM DATA FOR GRAPHICS REFRESH
440 DIM V(1000),T(1000) 'ARRAY FOR THERM. CALIBRATION TABLE (e.g. DIODE V.T)
450 DIM X(1000),Y(1000) 'ARRAY OF COMPARISON DATA FOR GRAPHICS
450 ON ERROR GOTO 5400 '---ERROR TRAPPING
460 RESTORE 470
470 DATA 0,1,1,0,0,1,1
480 READ CUR,SCALEX,SCALEY,DEL,DELY,GO8,G1 %,INVT 'Default Params
490 DATA "<INACTIVE" >","<ACTIVE> "
500 READ INACTS,ACTS,CSETS=NACTS:CGSETS=NACTS
504 '---- GPIB HSV ADDRESSES & METER PARAMS
505 DATA "26","14","KEITHLEY 181/199/197","KEITHLEY 181/199/197",5,5
506 READ XADDRS,YADDRS,MO9,MYS,NXM,NYM

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510 '  
520 'GRAPHICS DEFAULT PARAMETERS  
530 RESTORE 550  
540 READ XMIN,XMAX,YMIN,YMAX  
550 DATA 0,200,0,200  
560 READ X0,Y0,X2,Y2  
570 RESTORE 390  
580 READ X5,Y5,X7,Y7  
590 DATA "X-AXIS(UNITs)," "Y-AXIS(UNITs)," "TITLE OF X VS Y GRAPH"  
600 RESTORE 620  
610 READ DXPIX,DXPIX,XPXO,YPXO ' AXIS CONSTANTS IN PICTLES  
620 DATA 530,530,30,13  
630 RETURN ' TO MAIN PROGRAM  
640 '  
650 '  
700 ' *** SIGN-ON HARDWARE SETTINGS MESSAGE ***  
710 CJS: PRINT CHR$(7)  
720 PRINT: PRINT * ' *** HARDWARE SETTINGS ***  
730 PRINT 1: X-INPUT: GPB Address: "XADDR:" Meter ID: "MXS"  
740 PRINT 2: Y-INPUT: GPB Address: "YADDR:" Meter ID: "MY$"  
750 PRINT  
760 INPUT" ENTER SELECTION # (C/R) TO CONTINUE: ",ICOD  
770 ON ICOD GOTO 790,810  
780 RETURN ' TO MAIN PROGRAM  
790 INPUT" ENTER NEW GPB ADDRESS FOR X-INPUT: " XADDR  
791 GOSUB 850 '-- MIDIER ID CHOICES FOR READING STRING MASKING  
792 INPUT" ENTER X-INPUT Meter ID CODE (DIFFERENT = PREVIOUS): ",NMT  
794 IF NMT < > 0 THEN NM=NMT ELSE 830  
796 GOSUB 900: M$=MS: NM=NMSK ' ASSIGN METER ID NAME & MASKING DATA  
800 XADDR$=STR$(XADDR): GOTO 720  
810 INPUT" ENTER NEW GPB ADDRESS FOR Y-INPUT: " YADDR  
811 GOSUB 850 '-- MIDIER ID CHOICES  
812 INPUT" ENTER Y-INPUT Meter ID CODE (DIFFERENT = PREVIOUS): ",NMT  
814 IF NMT < > 0 THEN NM=NMT ELSE 820  
816 GOSUB 900: M$=MS: NY=NMSK ' ASSIGN METER ID NAME & MASKING DATA  
820 YADDR$=STR$(YADDR): GOTO 720  
830 '  
840 '  
850 ' *** ASSIGN STRING MASKING PARAMS FOR Meters ***  
854 PRINT ' ' ' Meter ID Codes ***  
855 PRINT 1: KEITHLEY 181.197  
856 PRINT 2: FLUKE 8840A  
860 RETURN  
870 '  
880 '  
890 '  
900 ' *** ASSIGN METER ID NAME ***  
910 ON NM GOTO 930,940  
920 PRINT CHR$(7): PRINT "< < WRONG METER ID > >": RETURN 230  
930 M$="KEITHLEY 181/197”: NMSK=5: RETURN  
940 M$="FLUKE 8840A": NMSK=1: RETURN  
950 '  
960 '  
1000 SCREEN 0: CJS  
1010 GOSUB 550 '-- INCREMENT EXTENSION ON DATA FILENAME  
1020 PRINT: PRINT: PRINT * ' *** SET-UP PARAMETERS ***  
1030 PRINT 1: FILENAME OF SETUP AND GRAPHICS PARAMETERS TO USE: "PUF$"  
1040 PRINT 2: FILENAME OF SETUP AND GRAPHICS PARAMETERS TO SAVE TO: "PSF$"  
1050 PRINT 3: X-VOLTAGE SCALE FACTOR (Signal/Meas V): "SCALEX"  
1060 PRINT 4: X-SIGNAL STEP SIZE: "DELX"  
1070 PRINT 5: Y-VOLTAGE SCALE FACTOR (Signal/Meas V): "SCALEY"  
1080 PRINT 6: Y-SIGNAL STEP SIZE: "DELY"  
1090 PRINT 7: DATA FILENAME: "DNMS"  
1100 PRINT ' TITLE: "TITLES"  
1110 PRINT 8: THERMOM. CAL. TABLE FILENAME (for X-signal conversion): "TINF$"  
1115 PRINT ' TITLE: "THT$"  
1120 PRINT 9: NO. OF SAMPLES IN DIGITAL FILTERING: "NHF$"  

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1130 PRINT \*10: SCREEN GRAPHICS PARAMETERS SETUP: \*:GSFM
1135 PRINT \*11: EXIT PROGRAM
1140 PRINT
1150 INPUT " > ENTER SELECTION # (<CR> TO EXECUTE): \*:ICODE
1160 ON ICODE GOTO 1400,1430,1290,1510,1180,1200,1220,1380,1380,1330,1335
1170 RETURN 'TO MAIN PROGRAM
1180 INPUT ' ENTER X- VOLTAGE SCALE FACTOR (Signal/Screen): \*:SCALEX
1190 GOTO 1200
1200 INPUT ' ENTER Y-SIGNAL STEP SIZE: \*:DELY
1210 GOTO 1200
1220 INPUT ' INPUT DATA FILENAME(EXT .DAT WILL BE ADDED IF NOT ENTERED): \*:DNMS
1230 IF DNMS="" THEN 1280
1240 PRINT" ENTER 80 CHARACTER DATA SET TITLE(DEFAULT=PREVIOUS): \*:INPUT**,DUM
1250 IF DUM="" THEN 1270
1260 TITLES=DUM
1270 FOR J=1 TO LEN(DNMS): IF MID$(DNMS,1,J)<"." THEN NEXT J ELSE 1280
1272 DNMS=DNMS+.D10
1280 GOTO 1200
1290 INPUT ' ENTER X- SUGNAL SCALE FACTOR (Signal/Screen): \*:SCALEY
1300 GOTO 1200
1310 INPUT ' ENTER X-SIGNAL STEP SIZE: \*:DEL
1320 GOTO 1200
1330 GOSUB 2250 ' Define Graphics Parameters
1332 GOTO 1200
1335 GOSUB 4500: END ' Store Params TO FILE AND EXIT
1340 GOTO 1200
1350 INPUT' ENTER THERMOM. CALIB. TABLE FILENAME(EXT .CAL WILL BE ADDED): \*:THNMS
1360 IF THNMS="" THEN 1370 ELSE THNMS=THNMS+.CAL
1365 GOSUB 3900 ' READ IN THERM. CALIB. DATA...
1370 GOTO 1200
1380 INPUT ' ENTER NO. SAMPLES IN DIGITAL FILTERING: \*:NFILT
1390 GOTO 1200
1400 INPUT ' ENTER FILENAME FOR SETUP PARAMS. TO USE(EXT .PAR WILL BE ADDED): \*:PFLS
1410 IF PFLS="" THEN 1420 ELSE PFLS=PFLS+.PAR
1420 GOSUB 4180; GOTO 230 ' --READ IN SETUP AND GRAPHICS PARAMS
1430 INPUT ' ENTER FILENAME FOR SETUP PARAMS. TO SAVE TO (.PAR WILL BE ADDED): \*:PSFLS
1440 IF PSFLS="" THEN 1450 ELSE PSFLS=PSFLS+.PAR
1450 GOTO 1200
1460
1500 "***OPEN DATA FILE ***
1510 IF DNMS="" THEN 1550
1520 OPEN "0",1,DNMS
1530 PRINT #1, TITLES
1540 PRINT #1, "X-signal Y-signal"
1550 RETURN
1560 ' "***INITIALIZATION FOR DATA ACQU. ***
1570 GOSUB 4050 ' PRINT MESSAGE AT SCREEN BOTTOM
1580 L=0 ' INITIALIZE DATA ARRAY INDEX
1590 GOSUB 4850 ' --ESTABLISH COMMUNICATION WIPERSONAL AB
1600 GOSUB 4930 ' --SIGNON MESSAGE
1610 GOSUB 5050 ' --ASSIGN REMOTE MODE ADDRESSES
1620 FILE=1 ' INITIALIZE FOR DATA SCREEN PRINTOUT
1630 GOSUB 1500 ' --OPEN DATA FILE
1640 I=VXFLG=0 ' --FLAG FOR FIRST TIME THRU
1700 PRINT ' "**Beginning Data Acquisition ***"
1710 RETURN 'TO MAIN PROGRAM
1720 ' "1730 ' "1750 ' "** TAKE DATA SAMPLE ***
1760 "-- OPB INPUT --
1770 GOSUB 5200 ' -- FIND AVG OF NFILT OPB READINGS
1790 YX=SUMX*SCALEX; YY=SUMY*SCALEY
1790 RETURN 'TO MAIN PROGRAM
1800 ' "1810 ' "186
1830 "*** DATA TEST FOR OUTPUT ***
1840 IF INVPLG = 0 THEN VX = VX: VYT = VY: RETURN 'FIRST TIME THROUGH
1870 DEL VX = VX: VX = DEL VX
1880 IF IDATPLG = 0 THEN 1920
1890 IF INV < > 'T' AND INV < > 'P' THEN PRINT 'MANUAL STORE'
1900 PRINT CHR$(18); '--- BELL TO INDICATE MANUAL DATA STORAGE
1910 IF pl = 0 THEN 1970
1920 IF pl = 0 THEN 1970
1930 IF ABS(DEL VX) = 0 THEN 1970
1940 IF ABS DEL VX = 0 THEN 1970 "STORE DATA
1950 IF ABS(DEL VX) = 0 THEN 1970 ELSE RETURN 260 "TAKE MORE DATA
1970 VX = VX: VYT = VY: RETURN 'TO MAIN PROGRAM
1980 ' 1990
2000 "*** PRINT VALUES ON DISK ***
2010 I = I + 1: Y(I) = VY 'INCREMENT INDEX
2020 IF THNS = ' ' THEN X(I) = VX: GOTO 2040
2030 X(I) = VX
2040 IF INMS = ' ' THEN 2060
2050 PRINT #1, X(I), Y(I)
2060 RETURN 'TO MAIN PROGRAM
2070 ' 2080
2100 "*** TEST TO REDEFINE GLOBAL GAIN ***
2110 IF VST = 0 THEN G% = 1: GOTO 2150
2120 IF VST = 1 THEN G% = 2: GOTO 2150
2130 IF VST = 2 THEN G% = 3: GOTO 2150
2140 IF G% = 4 THEN 2070
2150 "RETURN
2160 IF VST = VST "S = VX 'THEN G% = G%: GOSUB 1790 'RETURN 'CHANGE TO NEW X-GAIN
2170 G% = G%: GOSUB 1790 'CHANGE TO NEW Y-GAIN
2180 RETURN
2190 ' 2200
2210 ' 2220 "*** GRAPHICS PARAMETERS ***
2240 GSETS = ACRS 'SCREEN GRAPHICS ACTIVE
2270 PRINT: PRINT: PRINT: "*** SCREEN GRAPHICS PARAMETERS ***
2290 PRINT ' 1: X-axis Xmin, Xmax: ', XMIN, XMAX
2290 PRINT ' 2: Y-axis YMIN, YMAX: ', YMIN, YMAX
2300 PRINT ' 3: X-axis label: ', X
2300 PRINT ' 4: Y-axis label: ', Y
2300 PRINT ' 5: GRAPHTitle: ', T
2325 PRINT ' 6: COMPARISON DATA SET FILENAME: ', GCMPLS
2325 PRINT ' 7: TITLE: ', GTS
2327 PRINT ' 7: VIEW COMPARISON DATA SET: ', GSETS
2330 PRINT
2340 INPUT: Enter selection # (<1-5> TO MAIN MENU): ', ICODE
2350 ON ICODE GOTO 2370, 2430, 2430, 2430, 2430, 2430
2360 GOTO 2490
2370 INPUT ' ENTER X-axis Xmin, Xmax: ', XMIN, XMAX
2380 GOTO 2270
2390 INPUT ' ENTER Y-axis Ymin, Ymax: ', YMIN, YMAX
2400 GOTO 2270
2410 INPUT ' ENTER X-axis label: ', X
2420 GOTO 2270
2430 INPUT ' ENTER Y-axis label: ', Y
2440 FOR J = 1 TO LEN(Y): IF MID$(Y, J, 1) <> ' ' THEN NEXT J
2450 Y = LEFT$(Y, J - 1): J = LEN(Y) - J + 1: Y = RIGHT$(Y, J)
2460 GOTO 2270
2470 INPUT ' ENTER Graph Title: ', T
2480 GOTO 2270
2490 INPUT: Enter DATA SET FILENAME: ', GCMPLS
2450 GOSUB 5900: GOTO 2270 'READ IN DATA SET FROM FILE
2453 INPUT: VIEW PLOT OF DATA SET ('Y = YES?'): ', ANS
2454 IF ANS = 'Y' OR ANS = 'N' THEN GSETS = ACRS ELSE GSETS = INACTS: GOTO 2270
2458 GOSUB 2490 'DEFINE GRAPH AXES RANGES
2458 GOSUB 5900 'PLOT DATA SET
2487 GOSUB 4111 'PRINT MESSAGE AT SCREEN BOTTOM
2488 IF INK$ = " " THEN 2488 ELSE SCREEN 0: GOTO 2270
2489 '  
2490 XRN=$=XMAX-XMIN YRN=$=YMAX-YMIN
2500 XMIN$=STR$(XMIN); XMAX$=STR$(XMAX)
2510 YMIN$=STR$(YMIN); YMAX$=STR$(YMAX)
2520 GOSUB 2610: GOSUB 2660 ' DEFINE FUNCTION TO CALC COORD IN PIXELS
2530 RETURN
2540 '  
2550 '  
2600 '*** FN TO CALCULATE Y IN SCREEN PIXELS ***
2610 DEF FNYPY$(YVAR,YMIN,YRN,DYPIX,YPIX0)=-(YVAR-YMIN)*DYPIX*YRN+YPIX0+DYPIX
2620 RETURN
2630 '  
2640 '  
2650 '*** FN TO CALCULATE X IN SCREEN PIXELS ***
2660 DEF FNXPX$(XVAR,XMIN,XRN,DXPIX,XPIX0)=(XVAR-XMIN)*DXPIX*XRN+XPIX0
2670 RETURN
2680 '  
2690 '  
2700 '*** PLOT OR PRINT DATA ***
2710 IF INK$ <> " " THEN IF INK$ <> " " THEN 2740
2720 IF FLGS<="L" THEN 2780
2730 FLGS="L": GOSUB 3050: GOSUB 4050: RETURN 'LIST DATA TO CURRENT I
2740 IF GSE$="NACT": THEN 2780
2750 IF INK$ <> " " THEN IF INK$ <> " " THEN 2780
2760 IF FLGS<>"P" THEN 2786
2770 FLGS="P": GOSUB 2900: GOSUB 4050: RETURN 'PLOT DATA TO CURRENT I
2780 IF FLGS="L": THEN PRINT (X$),Y$): RETURN 'TO MAIN PROGRAM
2790 IF GSE$="NACT": THEN 2740
2800 XP=FNXPX$(X$),XMIN,XRN,DXPIX,XPIX0)
2805 IF ABS(X$)>10000 THEN 2840 '---OUT OF RANGE
2810 YP=FNYPY$(Y$),YMIN,YRN,DYPIX,YPIX0)
2815 IF ABS(Y$)>10000 THEN 2840
2820 PSET (XP,YP) ' PLOTS POINT
2830 'CIRCLE (XP,YP),3 'PLOTS CIRCLE
2840 RETURN 'TO MAIN PROGRAM
2850 '  
2860 '  
2900 *** REFRESH PLOT OR PRINT DATA UP TO CURRENT POINT ***
2910 CLS: GOSUB 3150: GOSUB 3500 'DRAW AND LABEL AXES
2920 FOR J = 1 TO 1
2930 XP=FNXPX$(X$),XMIN,XRN,DXPIX,XPIX0)
2940 IF ABS(X$)>10000 THEN 2970 '---OUT OF RANGE
2940 YP=FNYPY$(Y$),YMIN,YRN,DYPIX,YPIX0)
2945 IF ABS(Y$)>10000 THEN 2970
2950 'CIRCLE (XP,YP),3
2960 TSET (XP,YP)
2970 NEXT J
2975 IF CCSE$=" NACT": THEN RETURN
2976 IF CCSE$=" NACT": THEN GOSUB 5920 ' PLOT COMPARISON DATA
2980 RETURN
3000 '  
3010 '  
3050 *** PRINT DATA ON SCREEN ***
3060 SCREEN 0: CLS
3070 J1=120: IF J1<0 THEN J1=1
3080 FOR J = J1 TO 1
3090 PRINT (X$),Y$(J)
3100 NEXT J
3110 RETURN
3120 '  
3130 '  
3150 *** SUB TO DRAW GRAPH AXES ***
3160 SCREEN 9 'HE RES GRAPHICS SCREEN
3170 CLS
3180 TSET (60,15)
3150 DWN = 300; RGT = 550; TICKU = 30; TICKR = 55; ZERO = 0
3200 FOR J = 1 TO 10; DRAW"D = TICKU; NM + 550, 0; "NEXT J " --- LEFT VERTICAL AXIS
3210 FOR J = 1 TO 10; DRAW"R = TICKR; NM + 0, 300; "; NEXT J '' --- BOTTOM HORIZONAL AXIS
3220 DRAW"J = DWN; L = RGT;*
3230 RETURN
3240 ' 3250 ' 3300 "*** SUB TO LABEL AXIS ***"
3310 IF LENS(X$) > 60 THEN XS = LEFTS(X$; 60) ' TRUNCATE IF TOO LONG
3320 AX = 44 - .5 * LEN(X$)
3330 LOCATE 24, AX; PRINT XS;
3340 IF LENS(Y$) > 9 THEN YS = LEFTS(Y$; 9) ' TRUNCATE IF TOO LONG
3350 TAX = 5 - .5 * LEN(Y$)
3360 LOCATE 12, TAX; PRINT YS;
3370 IF LENS(Y$) > 0 THEN YS = LEFTS(Y$; 9)
3380 TAX = 5 - .5 * LEN(Y$)
3390 LOCATE 11, TAX; PRINT YS;
3400 IF LENS(T$) > 70 THEN TS = LEFTS(T$; 70) ' TRUNCATE IF TOO LONG
3410 TAX = 44 - .5 * LEN(T$)
3420 LOCATE 11, TAX; PRINT T$;
3430 LOCATE 24, 12 - LEN(X$) - 1; PRINT XMIN;
3440 IF XMAX$ = "" THEN 3460
3450 LOCATE 24, 81 - LEN(XMAX$); PRINT XMAX$;
3460 LOCATE 23, 16 - LEN(YMIN$); PRINT YMIN;
3470 LOCATE 2, 10 - LEN(YMAX$); PRINT YMAX$;
3480 RETURN
3490 ' 3500 ' 3550 ' *** SUB TO CHECK KEYBOARD STATUS ***
3560 INS = INKEYS$
3570 IF INS = "" THEN RETURN
3580 IF INS = CHR(13) THEN KEYFLAG = 1: GOTO 3710 ' MANUAL DATA STORAGE
3590 INKS = INS
3600 IF INKS < "*" AND INKS < > "q" THEN 3610
3610 IF INKS = "" THEN 3640 ' DATA FILENAME
3620 CLOSE #1; GCSUB 6000 ' --- REWRITE DATA TO FILE IN STD FORMAT
3630 SCREEN 0: INPUT "ANOTHER DATA SET? (Y/N):", ANS$2
3640 IF ANS$2 = "Y" OR ANS$2 = "y" THEN 3670
3650 ON ERROR GOTO 0 ' DISABLE ERROR TRAPPING
3660 CLS: END
3670 CLOSE RETURN240 ' TO MAIN PROGRAM AT MENU
3680 IF INKS < > "t" THEN IF INKS < > "Y" THEN RETURN
3690 IF INKS < > "Y" THEN IF INKS < > "t" THEN RETURN
3700 RETURN 320 ' TO MAIN PROGRAM AT FLT OR PRINT DATA
3710 RETURN 250 ' TO MAIN PROGRAM AT TAKE ONE DATUM
3720 ' 3730 ' 3750 "*** SUB TO INTERPOLATE TEMPERATURE FROM DIODE T,V TABLE ***"
3760 IF THNM$ = "" THEN RETURN ' TO MAIN PROGRAM
3770 VX$ = VX
3780 NLO = 1: NH = NDATA ' LOW AND HI INDICES OF TABLE DATA
3790 N = (NH + NLO)/2 ' INTEGER DIVIDE: TABLE INDEX TO BE COMPARED TO DATUM
3800 IF VX < VN THEN NH = N: GOTO 3720
3810 NLO = N
3820 IF NH < NLO + 1 THEN GOTO 3790
3830 T = T(NH) + (VN - VN(H)) * (T(NH) - T(NLO)) / (VN(NH) - VN(NLO))
3840 RETURN
3850 ' 3860 ' 3900 "*** SUB TO READ IN THERM. CALIB DATA ***"
3910 IF THNMS = "" THEN RETURN
3920 IF THNMS$ = "THNMS THEN RETURN ' no need to read data again
3930 THNMS$ = THNMS
3940 PRINT*** ' Reading in therm. calibration table ???
3950 OPEN "I", #1, THNMS
3952 INPUT #1, THTTS$ ' --- TITLE OF DATA SET
3960 INPUT #1, NDATA

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3970 FOR J = 1 TO NDATA
3980 INPUT #1,Y(J),T(J)
3990 NEXT J
4000 CLOSE #1
4010 RETURN
4020 '  
4030 ' **** PRINT MESSAGE AT BOTTOM OF SCREEN ****
4040 IF GSET$="ACT$ THEN 4060
4050 CLS: LOCATE 25,1: PRINT"PRESS: <C/R> STORE PT. <Q> QUIT: 
4060 LOCATE 1,1: GOTO 4110
4070 LOCATE 25,1: PRINT"PRESS: <C/R> STORE PT. <Q> QUIT <P> PLOT RESTORE <L> LIST;
4080 LOCATE 24,1
4090 RETURN
4100 LOCATE 25,1: PRINT" PRESS <C/R> TO CONTINUE: 
4110 RETURN
4120 LOCATE 24,1
4130 RETURN
4140 '  
4150 ' *** READ IN SETUP AND GRAPHICS PARAMETERS ***
4160 IF FULS="** THEN RETURN
4170 OPEN "",#1, FULS
4180 PRINT"**** RETRIEVING PARAMETERS FROM: ": FULS; "****
4190 ' --SETUP PARAMETERS
4200 INPUT#1,PSL
4210 INPUT #1,SCALEX
4220 INPUT #1,DEL
4230 INPUT #1,SCALEY
4240 INPUT #1,DLY
4250 INPUT #1,DMNS
4260 DUMS=TITLE$ 
4270 INPUT #1,TMNS$ 
4280 INPUT #1,NVLT
4290 INPUT #1,GSET$ 
4300 ' --GRAPHICS PARAMETERS
4310 INPUT #1,XMIN,XMAX
4320 INPUT #1,YMIN,YMAX
4330 INPUT #1,XY$ 
4340 INPUT #1,XY$ 
4350 INPUT #1,TY$ 
4360 INPUT #1,TY$ 
4370 ' --GET & MEETER PARAMS
4380 INPUT#1,XADDR$ 
4390 INPUT#1,YADDR$ 
4400 INPUT#1,NX$ 
4410 INPUT#1,MY$ 
4420 INPUT#1,NYM,NYM
4430 ' -- COMPARISON GRAPHICS DATA FILE INFO
4440 INPUT#1,CCNUM$ 'FLAG FOR GRAPHICS COMPARISON
4450 CLOSE #1
4460 IF GSET$="ACT$ THEN GOSUB 3500: GOSUB 2490 ' --READ IN COMP DATA SET
4470 GOSUB 3900 ' --READ IN THE KM CALIB. DATA
4480 RETURN
4490 '  
4500 ' *** SAVE SETUP AND GRAPHICS PARAMETERS TO FILE ***
4510 IF FULS="** THEN RETURN
4520 OPEN "O",#1, FULS
4530 PRINT"*** STORING PARAMETERS TO: ": FULS; "***
4540 ' --SETUP PARAMETERS
4550 PRINT#1,PSL
4560 PRINT#1,SCALEX
4570 PRINT#1,SCALEY
4580 PRINT#1,DLY
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4590 PRINT#1, DNMS
4600 PRINT#1, TITLES$
4610 PRINT#1, THNMS$
4620 PRINT#1, NFILT$
4630 PRINT#1, GSETS$
4640 "GRAPHICS PARAMETERS"
4650 PRINT#1, XMIN, XMAX
4660 PRINT#1, YMIN, YMAX
4670 PRINT#1, N$
4680 PRINT#1, Y1$
4690 PRINT#1, Y2$
4700 PRINT#1, T$
4710 "GRID & METER PARAMS"
4720 PRINT#1, XADDR$
4730 PRINT#1, YADDR$
4740 PRINT#1, MX$
4750 PRINT#1, MY$
4760 PRINT#1, NXM, NYM$
4770 "COMPARISON GRAPHICS DATA FILE INFO"
4780 PRINT#1, OCMP$ = "FILE NAME G: COMPARISON DATA SET"
4790 PRINT#1, OCSET$ = "FLAG FOR ACTIVE GRAPHICS COMPARISON"
4800 PRINT#1, CLOSE #1
4810 RETURN
4820 "$"
4830 ' *** Establish communications with Personal488 ***
4840 OPEN "DEVIERBOUT" FOR OUTPUT AS #2
4870 ' Read Personal488
4880 DCNLJ2,, "BREAK"
4890 PRINT#2,, "RESET"
4900 ' Open file to read responses from Personal488
4910 OPEN "DEVIERBWIN" FOR INPUT AS #3
4920 ' Enable SEQUENCE error detection by Personal488
4930 PRINT#2,, "FAIL ERROR"
4940 PRINT#2,, "TIME OUT 15"
4950 RETURN
4960 ' 
4970 ' *** Read the siqron and revision message ***
4980 PRINT#2,, "HELLO"
4990 INPUT#3, A$
5000 PRINT#1, A$
5010 RETURN
5020 ' 
5030 ' *** Put the 197's into REMOTE ***
5040 PRINT#2,, "REMOTE", YADRES$
5070 PRINT#2,, "REMOTE", YADDR$
5080 RETURN
5090 ' 'AUTO range' Y: Execute. P: Disable filter
5100 PRINT#2,, "OUTPUT", YADRES$,, "PBX"
5110 PRINT#2,, "OUTPUT", YADRES$,, "PBIX"
5120 RETURN
5130 ' 
5140 ' 
5150 ' 
5200 ' *** Find the average of Navg readings ***
5210 SUMX = 0: SUMY = 0
5220 FOR J = 1 TO NFILT
5230 PRINT#2,, "OUTPUT", XADDR$, "PBX"
5240 PRINT#2,, "ENTER", XADDR$
5340 INPUT#3$, S$: VALX = VAL.MIDS$(S$, NXYM)
5350 IF ABX$(VALX$) > 100 THEN GOSUB 5530: GOTO 5210 ' ***START OVER - BAD READING ***
5520 SUMX = SUMX + VALX$
5530 PRINT#2,, "OUTPUT", YADRES$,, "PBIX" ' Use front panel range
5570 PRINT#2,, "ENTER", YADRES$
5580 INPUT#3$, R$: VALY = VAL.MIDS$(R$, NYM)
5290 IF ABS(VALY) > 100 THEN COSUB 5350: GOTO 5210 "---START OVER"
5300 SUMY = SUMY + VALY
5310 NEXT J
5320 SUMX = SUMX/NFILT: SUMY = SUMY/NFILT
5330 RETURN
5340 '  
5350 ' *** PRINTOUT MESSAGE FOR BAD READING ***
5360 PRINT CHR$(7);: IF FLO$="L" OR FLO$="I" THEN PRINT"> > BAD READING < <";:R$  
5370 RETURN
5380 '  
5390 '  
5400 ' *** ERROR TRAPPING ***
5410 PRINT CHR$(7);: ' ---BILL TO INDICATE ERROR
5420 IF ERR < > 53 THEN RESUME 260 --TRY TO TAKE MORE DATA
5425 PRINT" > > BAD FILENAME < <": FOR J = 1 TO 1000: NEXT J: RESUME 240  
5440 '  
5450 '  
5500 ' *** INCREMENT EXTENSION ON DATA FILENAME ***
5510 PRINT CHR$(7)
5520 IF DNMS="" THEN RETURN
5530 FOR J = 1 TO LEN(DNMS): IF MID$(DNMS,J,J) < > ":" THEN NEXT J  
5540 J = J + 1
5550 EXTS = RIGHT$(DNMS,J): DNMS = LEFT$(DNMS,J-1)
5560 EXT = VAL(RIGHT$(EXTS,1)): IEXT = IEXT + 1
5570 IEXTS = RIGHT$(STR$(IEXT,1))
5580 EXTS = LEFT$(EXTS,3) + IEXTS
5590 DNMS = DNMS + EXTS
5600 RETURN
5610 '  
5620 '  
5630 ' **** READ IN DATA SET FOR GRAPHICS COMPARISON ****
5640 PRINT"**** RETRIEVING COMPARISON DATA SET ****"  
5650 IF OCMPL$="" THEN RETURN
5660 OPEN#, ":", OCMPL$  
5670 INPUT#, CTFL$: ' ---TITLE OF FILE DATA
5680 INPUT#, NDATG
5690 XMX = XG(1): XMN = XG(1): YMNX = YG(1): YMN = YG(1)
5700 FOR J = 1 TO NDATG
5710 INPUT#, XG(J), YG(J)
5720 IF XG(J) > XMX THEN XMX = XG(J): GOTO 5857
5730 IF XG(J) < XMN THEN XMN = XG(J)
5740 IF YG(J) > YMX THEN YMX = YG(J): GOTO 5850
5750 IF YG(J) < YMN THEN YMN = YG(J)
5760 NEXT J
5770 CLOSE #1
5780 PRINT"XMIN: *,XMN,*,XMAX: *,XMX  
5790 PRINT"YMIN: *,YMN,*,YMAX: *,YMX  
5800 RETURN
5810 '  
5820 '  
5830 ' *** PLOT OF COMPARISON DATA ***
5840 CLS: GOSUB 5150: GOSUB 3300 'DRAW AND LABEL AXES
5850 FOR J = 1 TO NDATG
5860 XP = FNXPX(XG(J),XMN,XRNG,DXPX,XP0)  
5870 IF ABS(XP) > 10000 THEN 3970 '---OUT OF RANGE
5880 YP = FNPYX(YG(J),YMN,YRNG,DYPX,YP0)
5890 IF ABS(YP) > 10000 THEN 3970
5900 CIRCLE (XP,YP);  
5910 SET (XP,YP)  
5920 NEXT J
5930 RETURN
5940 '  
5950 '  
5960 ' **** REWRITE DATA TO FILE ****
5970 IF UNMS="" THEN RETURN
5980 OPEN#",#: UNMS  
5990 PRINT"**** STORING DATA ARRAY TO FILE ****  
6000 PRINT#, TITLES
6010 PRINT#,1 ' ---NO. OF DATA IN SET

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Appendix E. Monte Carlo Computational Information

In the Monte Carlo simulations, the percolation paths were allowed 64 degrees of freedom at each increment along each current path. This is preferable over the choice of only four directions used in many percolation theories published elsewhere,\(^1,\(^2\) since the Hall effect, unlike most other transport properties, is highly sensitive to the current direction. However, since the high-\(T_c\) materials are best described as quasi-two dimensional superconductors, the current paths were confined to remain within a two dimensional conduction plane. Similarly, the current paths were also constrained to remain within a conduction bridge of fixed width. While maintaining these constraints, increments of fixed spatial distances were made at each step along the percolation path. Thus, instead of defining a matrix of resistivities as modelled by others,\(^1\) the simulations here required predefined \(T_c\) distributions in terms of the two spatial coordinates \((x_i, y_i)\). A total of 60 Gaussian \(T_c\) distributions were constructed, ranging from purely homogeneous to moderately inhomogeneous \((\Delta T_c \leq 6K)\), while maintaining as much randomness between the various distributions as possible. Moreover, in each simulation ten equally spaced current paths were started well ahead of the Hall measurement region to allow ample opportunity for the current
paths to converge towards the regions of least resistance. Immediately upon the reaching the Hall terminals, the integration of $R_H$ (described in detail in the main text) was initiated. A total of $\sim 10^6$ increments were allowed for each path while in the Hall measurement region in order to obtain reasonable convergence.

To a good approximation, the path of least resistance will be obtained if the current is required to move in the local direction of least resistance at each increment. In accomplishing this, an "effort" value $\epsilon_j$ was assigned to each of the 64 possible directions where

$$
\epsilon_j = \begin{cases} 
\frac{\rho \left[ r_i \cdot \frac{T - (T_c - T_d)}{r_i^{N-1}} \right]}{2 - \cos(\theta)}, & \text{if } \theta_j = 180^\circ \\
0, & \text{otherwise.}
\end{cases}
$$

(94)

Here $\theta = 0^\circ$ is defined as the preferred forward direction. Since a complete reversal of the current direction is unphysical, $\epsilon_j$ is set to infinity whenever $\theta = 180^\circ$ or the current path reaches the edge of the defined bridge. The multiplicative term comes from the fact that a measured voltage is proportional to the spatial length of the measurement, i.e., $V \propto I \int \rho \, d\ell$. The summation term represents discrete radial scans, e.g., $r_{i+1} = r_i + C$, proportional to the "local" resistivities that originate from the spatial coordinate $(x_i, y_i)$ through a distance of roughly one bridge width. The step size $C$ is taken small enough to allow good convergence of the final results and depends on the spatial coarseness of the particular $T_c$ distribution. The "local" resistivities $\rho[(x_i, y_i), T, H]$ are obtained from a compiled table of in-field resistive transitions [(Figure 43)] taken on a coevaporated epitaxial thin film. For simplicity, the
effect of the "local" $T_c$ is approximated by a simple temperature shift of the representative resistive transitions. This is reasonable provided the $T_c$ distribution is on the order of only a few Kelvins. In Equation (94), $\langle T_c \rangle$ is the mean $T_c$ of the distribution and $T_{ci}$ is the $T_c$ at a radius $r_i$ from the point $(x_i,y_i)$. Finally, the "scanned" resistivities are divided by weight factors proportional to the surface area defined at each radius $r_i$ from the point $(x_i,y_i)$. These weight factors, e.g., $r_i^{N-1}$, depend on the effective dimensionality $N$, where in thin films, the dimensionality is set equal to two ($N=2$). Therefore, the unique numerical procedure described above provides a simple means of determining the apparent Hall coefficients in a variety of moderately inhomogeneous systems.
In-field resistive transitions obtained from a highly crystalline, coevaporated, epitaxial thin film of YBa$_2$Cu$_3$O$_7$. These transitions were utilized in the Monte Carlo simulations of the Hall effect transitions. "Local" resistivities were approximated by shifting these transitions up or down in temperature in order to represent the "local" deviations of the transition temperatures from the mean transition temperature.
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