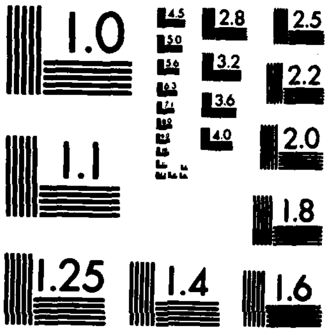
AD-A143 198 ELECTRICAL AND DIFFERENTIAL SCANNING CALORIMETRY STUDIES OF POLY(ETHYLENE..(U) NAVAL ACADEMY ANNAPOLIS MD DEPT OF PHYSICS J J FONTANELLA ET AL. MAY 84 TR-10 1/1

UNCLASSIFIED F/G 7/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

OFFICE OF NAVAL RESEARCH

[redacted]

Task No. NR 627-793

TECHNICAL REPORT NO. 10

ELECTRICAL AND DIFFERENTIAL SCANNING CALORIMETRY STUDIES OF POLY(ETHYLENE OXIDE) COMPLEXED WITH ALKALINE EARTH THIOCYANATES

by

John J. Fontanella & Mary C. Wintersgill

Prepared for Publication

in

Journal of Polymer Science: Polymer Physics Edition

U. S. Naval Academy
Department of Physics
Annapolis, MD 21402

May 1984

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 10	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ELECTRICAL AND DIFFERENTIAL SCANNING CALORIMETRY STUDIES OF POLY(ETHYLENE OXIDE) COMPLEXED WITH ALKALINE EARTH THIOCYANATES		5. TYPE OF REPORT & PERIOD COVERED Interim technical report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) JOHN J. FONTANELLA & MARY C. WINTERSGILL		8. CONTRACT OR GRANT NUMBER(s) [redacted]
9. PERFORMING ORGANIZATION NAME AND ADDRESS Physics Department U. S. Naval Academy Annapolis, MD 21402		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR No. 627-793
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Attn. Code 413, 800 N. Quincy St. Arlington, VA 22217		12. REPORT DATE May 1984 13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release and sale.
Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solid electrolytes, polymer electrolytes, poly(ethylene oxide), polymer salt complexes, electrical relaxation, electrical conductivity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Audio frequency dielectric relaxation measurements and differential scanning calorimetry studies have been performed on poly(ethylene oxide) (PEO) complexed with calcium and barium thiocyanate. The measurements were performed over the temperature range 5.5-300K. The relaxation spectrum for the complexed material consists of two peaks. The activation enthalpy for the peak

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

corresponding to the γ relaxation of pure PEO depends upon the size of the dopant cation. The activation enthalpy for the second peak is independent of the nature of the dopant cation and is very similar to that observed for the α_c relaxation observed in pure PEO. Next, the room temperature electrical conductivity for the complexed materials is much smaller than that for pure PEO and hence very much less than for PEO complexed with alkali metal salts. However, above T_g, the conductivity rises rapidly and is larger for the barium thiocyanate complexed PEO than for the calcium complexed material. Finally, the DSC studies show that an effect of the ions is to shift the glass transition temperature to high temperatures.

A-1

Electrical and Differential Scanning Calorimetry Studies of Poly(ethylene oxide) Complexed with Alkaline Earth Thiocyanates

John J. Fontanella, Mary C. Wintersgill, J.P. Calame
Physics Department
U.S. Naval Academy
Annapolis, Md. 21402

and

Carl G. Andeen
Physics Department
Case Western Reserve University
Cleveland, Ohio 44106

Synopsis

Audio frequency dielectric relaxation measurements and differential scanning calorimetry studies have been performed on poly(ethylene oxide) (PEO) complexed with calcium and barium thiocyanate. The measurements were performed over the temperature range 5.5-300K. The relaxation spectrum for the complexed material consists of two peaks. The activation enthalpy for the peak corresponding to the γ relaxation of pure PEO depends upon the size of the dopant cation. The activation enthalpy for the second peak is independent of the nature of the dopant cation and is very similar to that observed for the α_c relaxation observed in pure PEO. Next, the room temperature electrical conductivity for the complexed materials is much smaller than that for pure PEO and hence very much less than for PEO complexed with alkali metal salts. However, above T_g, the conductivity rises rapidly and is larger for the barium thiocyanate complexed PEO than for the calcium complexed material. Finally, the DSC studies show that one effect of the ions is to shift the glass transition temperature to higher temperatures.

INTRODUCTION

In recent papers the authors have presented electrical relaxation, electrical conductivity and differential scanning calorimetry (DSC) studies of pure poly(ethylene oxide) (PEO) and PEO complexed with alkali metal thiocyanates,[1] perchlorates,[2] iodides and trifluoromethane sulfonates.[3] In addition, the effect of high pressure on the electrical conductivity has been determined for several of the complexed materials[4] in order to gain information on the conductivity mechanism in these solid electrolytes. In the present paper, the work is extended to PEO complexed with alkaline earth thiocyanates.

EXPERIMENT

PEO (M.W. 5×10^6) was obtained from Polysciences, Inc. and $Ca(SCN)_2{:}4H_2O$ and $Ba(SCN)_2{:}3H_2O$ were obtained from Alfa Products. Both were dissolved in methanol at about 50°C in the ratio 6.5:1 polymer repeat unit to salt. The solution was cast on a teflon plate and allowed to dry in air. The materials were then vacuum dried at about 55°C. Thick, brittle films were the result.

No special precautions were taken to dry the polymer, salts or the methanol. The philosophy of this experiment was to treat all materials identically and identify differences which should then be due to the salts used to complex the polymer. However, it should be kept in mind that all measurements were performed in vacuum and, in fact, the effects described below were observed after the complexed samples had been annealed in vacuum at 100°C for several hours. Thus, none of the results are attributable to adsorbed water.

Aluminum electrodes were evaporated onto the samples in a two terminal configuration. For the barium thiocyanate complexed material, one electrode was about 1.5 cm in diameter and the other was about 2.3 cm. For the calcium thiocyanate complexed material, the electrodes were about 0.9 and 1.3 cm in diameter. The geometry was chosen to maximize the efficiency of the sample holder. This configuration limits the accuracy of the strength of the peaks to about 20% because eq. 1 given below is only approximate. However, the relative change in loss is much more accurate.

The measurements were performed in a Cryogenics Associates temperature controlled dewar. Eight different specimens can be measured simultaneously thus allowing a useful comparison of materials. The data were taken with the temperature held constant with approximately 45 min equilibration time at the highest temperatures decreasing to about 20 min at the lowest temperatures. Above 45K the temperature is measured using a Rosemount Eng. Co. platinum resistance thermometer and below 45K it is measured using a CryoCal Inc. germanium resistance thermometer. The temperature is controlled using a 27 Hz feedback temperature controller and in general was controlled to within 0.001K. The absolute temperature is accurate only to about 0.1K. Other results obtained using this system are given elsewhere.[1-5]

The loss measurements were made at the five audio frequencies, 10^2, $10^{2.5}$, 10^3, $10^{3.5}$ and 10^4 Hz using a fully automated, microprocessor controlled bridge constructed by one of the authors (C.G.A.) which is as sensitive and accurate as the best commercially available manual bridge. The complex dielectric constant, $\varepsilon^* = \varepsilon' - j\varepsilon''$, was determined from the data as follows. First, ε' at 300K and 1000 Hz was determined from the relation:

$$C = \frac{\varepsilon_o \varepsilon' A}{d} \tag{1}$$

where C is the value of the capacitance and d and A are the approximate thickness and area and ε_o is the permittivity of free space. The values of ε' at the other frequencies were then calculated assuming that the fractional change in ε' with frequency equals that for the capacitance. Due to a lack of thermal expansion coefficients, it was also assumed that the percentage change in ε' with temperature equals that for the capacitance. Next, values of ε'' at all temperatures were calculated using:

$$\varepsilon'' = G\varepsilon'/\omega C \tag{2}$$

where G/ω is the measured conductance divided by the angular frequency. Finally, the conductivity was calculated using:

$$\sigma = \varepsilon_0 \varepsilon'' \omega \tag{3}$$

The DSC measurements were performed using a DuPont 990 differential scanning calorimeter.

DISCUSSION

DSC Studies

The results of the DSC studies are shown in Figures 1 and 2. In both samples a small endothermic event is observed at about 60°C. This is associated with the melting of pure crystalline PEO in the samples. The presence of pure PEO is not surprising as no attempt was made to synthesize fully complexed material. No traces of amorphous PEO are indicated as no low temperature (-60°C) glass transition was observed. However a strong glass transition is observed in the calcium thiocyanate complexed material at about 35°C in both the as-prepared material and after quenching from 200°C. In the barium thiocyanate complexed material, the glass transition was observed at about 55°C after quench. The large increase in T_g for polyethers due to the incorporation of other inorganic salts is well known.[6]

Electrical Relaxation Studies

The results for ε'' at the three frequencies 10^2, 10^3 and 10^4 Hz are shown in Figures 3 and 4. Two relaxations are apparent. An approximate activation enthalpy, E, and "reciprocal frequency factor," τ_o, were determined for each sample from the relation:

$$\ln(\omega) = -\ln(\tau_o) - E/kT_{max} \tag{4}$$

The results for each peak are listed in Table I.

The enthalpy for the higher temperature peak in both materials is found to be approximately 0.5 eV. The similarity of the peak positions for this peak in both materials is obvious from Figure 5 where the 100 Hz data for both complexed materials are plotted. Further, there is a similar peak in pure PEO which is apparent from the Arrhenius plot in Figure 1d of ref. 1. The peak position is close to that for the mechanical relaxation reported by Connor et al.[7] and Kalfoglou,[8] which was labeled α_c. Since the DSC studies reported above show that there is some pure, crystalline PEO in the material, the higher temperature peak is attributed to the α_c relaxation in pure PEO, though the identification is tentative.

It is clear from Figure 5 that the lower temperature peaks in the complexed materials are different from the γ relaxation in pure PEO. In fact, the peak for the calcium thiocyanate material occurs at a lower temperature than for pure PEO while that for the barium thiocyanate occurs at a higher temperature. This trend is reflected in the activation enthalpies listed in Table I.

The results correlate with ion size considerations and are consistent with attributing the γ relaxation to hydroxyl groups. The γ relaxation has been variously attributed to a "crankshaft mechanism,"[9,10] "3-bond" or "4-bond" motions,[11,12] "chain end hydroxyl groups"[13] or the "$tg^+t \rightleftarrows tg^-t$" transition.[14] In previous papers on dielectric relaxation in ion containing PEO[1-4] the data were interpreted in terms of the "$tg^+t \rightleftarrows tg^-t$" transition. However, by preparing deuterated samples of PEO, the authors have recently obtained evidence that the γ relaxation in PEO is more likely to be due to hydroxyl groups at least part of which exist at chain ends as suggested by Hedvig.[13] That data will be presented elsewhere. The trends observed in the present work can then be explained as follows.

The effect of the ions is to modify the chain structure. Specifically, Ca^{2+} is smaller than the helical tunnel radius for pure PEO while Ba^{2+} is probably larger. Papke et al.[15] concluded that the ttg^+ttg^- PEO conformation has an inner tunnel radius of 0.13-0.15 nm and the Ca^{2+} ion has a radius of 0.1 nm while Ba^{2+} has a radius of 0.135 nm (effective coordination number of 6).[16] Consequently, if the cations reside within the helical tunnels, the effect of Ca^{2+} may be to "tighten" the helix thus making the motion of the contiguous hydroxyl groups easier (lower energy barrier). The effect of the Ba^{2+}, being larger than the tunnel radius, would then be expected to be opposite.

Considering the current interest in ion conducting PEO[1-4,9,17-24] the most important result of the present work is that at room temperature the electrical conductivity of the complexed material is less than for the "pure" PEO studied in the present work and thus many orders of magnitude lower than for PEO complexed with most alkali metal salts. This can be seen by comparing Figure 6, where the conductivities for the present samples are plotted, with the figures of reference 1. At 300 K and 100 Hz, for example, the effective electrical conductivity of the $Ba(SCN)_2$ complexed material is about 5×10^{-12} $(\text{ohm-cm})^{-1}$ and that for $Ca(SCN)_2$ complexed material is about twice as large. There is also a great deal of dispersio in this region with the conductivities approximately proportional to ω (ϵ'' approximately constant). These values are to be compared with a value of about 10^{-8} $(\text{ohm-cm})^{-1}$ for "pure" PEO[1] and typical values of about 10^{-5} $(\text{ohm-cm})^{-1}$ for PEO complexed with alkali metal salts. The most likely interpretation of the low conductivities is that the alkaline earth and thiocyanate ions form a non-conducting matrix at room temperature which has the additional effect of inhibiting the motion of the trace impurities which are presumably responsible for the conductivity in the "pure" PEO. A relevant observation is that samples of hot-pressed "pure" PEO show the same conductivity as the cast films. Consequently, the trace impurities are not introduced via the solvent used in casting the films and are probably present in the as-received polymer.

However, the conductivity in both samples rises rapidly with temperature above room temperature and particularly in the barium thiocyanate complexed material, reaches a relatively high value. The higher conductivity for the barium thiocyanate material is attributed to the large polarizability of the barium ion. This suggests that PEO complexed with lead thiocyanate, for example, should exhibit higher conductivities still.

Finally, it should be pointed out that the low room temperature conductivity and onset of the electrical conductivity at higher temperatures for the alkaline earth thiocyanate complexed materials is probably related to the higher temperature glass transition for these materials. Specifically, it has been suggested[15,17,18] that large amplitude polymer segmental motion is important for ion transport. Consequently, large ionic conductivities are only expected above T_g where the chains are mobile and thus a consistent interpretation of the present results can be obtained assuming ionic conductivity. However, it should be kept in mind that the nature of the charge carriers in these materials has yet to be determined.

SUMMARY

In summary, then, DSC and audio frequency electrical relaxation measurements on PEO complexed with AE thiocyanates have yielded the following results:

(1) T_g in the complexed materials is found to be shifted to higher temperatures than for pure PEO.

(2) The DR spectrum consists of two peaks. One peak is tentatively attributed to α_c for pure PEO. The position of the second peak which occurs in the γ relaxation region, is lower (higher) in temperature for the calcium (barium) thiocyanate complexed material than for pure PEO. This correlates with the fact that calcium is smaller than the tunnel radius while barium is larger.

(3) The room temperature σ for the complexed materials is smaller than for the "pure" PEO studied but rises rapidly above T_g and is larger for the

barium thiocyanate complexed material than for the calcium thiocyanate complexed material.

The authors would like to thank Al Tompa of Naval Surface Weapons Center, Naval Ordnance Station, Indian Head, Md. for providing the DuPont 990 DSC console. This work was supported in part by the Office of Naval Research.

References

1. J. J. Fontanella, M. C. Wintersgill, J. P. Calame and C. G. Andeen, Solid State Ionics, 8, 333 (1983).

2. M. C. Wintersgill, J. J. Fontanella, J. P. Calame, D. R. Figueroa and C. G. Andeen, Solid State Ionics, 11, 151 (1983).

3. M. C. Wintersgill, J. J. Fontanella, J. P. Calame and C. G. Andeen, unpublished work.

4. J. J. Fontanella, M. C. Wintersgill, J. P. Calame, F. P. Pursel, D. R. Figueroa and C. G. Andeen, Solid State Ionics, 9&10, 1139 (1983).

5. C. G. Andeen, J. J. Fontanella, M. C. Wintersgill, P. J. Welcher, R. J. Kimble and G. E. Matthews, Jr., J. Phys. C: Solid State Phys., 14, 3557 (1981).

6. A. Eisenberg and M. King, Ion-Containing Polymers, Academic Press, New York, 1977, pp. 45-48.

7. T. M. Connor, B. E. Read and G. Williams, J. Appl. Chem., 14, 74 (1964).

8. N. K. Kalfoglou, J. Polym. Sci. Polym. Phys. Ed., 20, 1259 (1982).

9. T. F. Schatzki, J. Polymer Sci., 57, 496 (1962).

10. R. F. Boyer, Rubber Rev., 35, 1303 (1963).

11. B. Valeur, J. Jarry, F. Geny and L. Monnerie, J. Polymer Sci.: Polymer Phys., 13, 667 (1975).

12. B. Valeur, L. Monnerie and J. Jarry, J. Polymer Sci.: Polymer Phys., 13, 675 (1974).

13. P. Hedvig, Dielectric Spectroscopy of Polymers, Adam Hilger Ltd., Bristol, 1977.

14. T. Suzuki and T. Kotaka, Macromolecules, 13, 1495 (1980).

15. B. L. Papke, M. A. Ratner and D. F. Shriver, J. Electrochem. Soc., 129, 1694 (1982).

16. R. D. Shannon, Acta Crystallogr., 32, 751 (1976).

17. M. B. Armand, J. M. Chabagno and M. J. Duclot, in Fast Ion Transport in Solids, J. N. Mundy and G. K. Shenoy, Eds., Pergamon Press, New York, 1979, p. 131.

18. B. L. Papke, M. A. Ratner and D. F. Shriver, J. Phys. Chem. Solids, 42, 493 (1981).

19. M. Leveque, J. F. Le Nest, A. Gandini and H. Cheradame, Makromol. Chem., Rapid Commun., 4, 497 (1983).

20. J. E. Weston and B. C. H. Steele, Solid State Ionics, 7, 81 (1982).

21. C. Berthier, W. Gorecki, M. Minier, M. B. Armand, J. M. Chabagno and P. Rigaud, Solid State Ionics, 11, 91 (1983).

22. C. C. Lee and P. V. Wright, Polymer, 23, 681 (1982).

23. P. R. Sorensen and T. Jacobsen, Polymer Bulletin, 9, 47 (1983).

24. F. L. Tanzella, W. Bailey, D. Frydrych, G. C. Farrington and H. S. Story, Solid State Ionics, 5, 681 (1981).

TABLE I

Activation parameters for the relaxations observed in pure and calcium and barium thiocyanate complexed poly(ethylene oxide).

Relaxation	Material	$\tau_o (10^{-14} s)$	E(eV)
α_c	$PEO_{6.5}Ba(SCN)_2:3H_2O$	36	0.48
γ	$PEO_{6.5}Ba(SCN)_2:3H_2O$	4.3	0.37
γ	PEO	6.0	0.33
γ	$PEO_{6.5}Ca(SCN)_2:4H_2O$	14	0.30

Figure Captions

Fig. 1. DSC thermograms for $PEO_{6.5}:Ca(SCN)_2:4H_2O$. The solid curve (Before) is for the as-prepared material. The dashed curve (After) is for the sample after being held at 200°C for 2 hr. then quenched to -100°C as rapidly as possible with the sample in the calorimeter using the cooling tower. The two curves are displaced for clarity.

Fig. 2. DSC thermograms for $PEO_{6.5}:Ba(SCN)_2:3H_2O$. The solid curve (Before) is for the as-prepared material. The dashed curve (After) is for the sample after being held at 200°C for 2 hr. then quenched to -100°C as rapidly as possible with the sample in the calorimeter using the cooling tower. The two curves are displaced for clarity.

Fig. 3. ε'' vs. T(K) for $PEO_{6.5}:Ca(SCN)_2:4H_2O$. Straight line segments connect the datum points and the frequencies are: dash, 100 Hz; solid, 1000 Hz; chain link 10,000 Hz.

Fig. 4. ε'' vs. T(K) for $PEO_{6.5}:Ba(SCN)_2:3H_2O$. Straight line segments connect the datum points and the frequencies are: dash, 100 Hz; solid, 1000 Hz; chain link 10,000 Hz.

Fig. 5. ε'' vs. T(K) at 100 Hz for various materials: solid, "pure" PEO; chain link, $PEO_{6.5}:Ca(SCN)_2:4H_2O$; dash, $PEO_{6.5}:Ba(SCN)_2:3H_2O$.

Fig. 6. $\mathrm{Log}_{10}(\sigma(\mathrm{ohm\text{-}cm})^{-1})$ vs. 1000/T (K^{-1}) for $PEO_{6.5}$:$Ba(SCN)_2$:$3H_2O$ (upper set of curves) and $PEO_{6.5}$:$Ca(SCN)_2$:$4H_2O$ (lower set of curves). The frequencies are: dash, 100 Hz; solid, 1000 Hz; chain link 10,000 Hz.

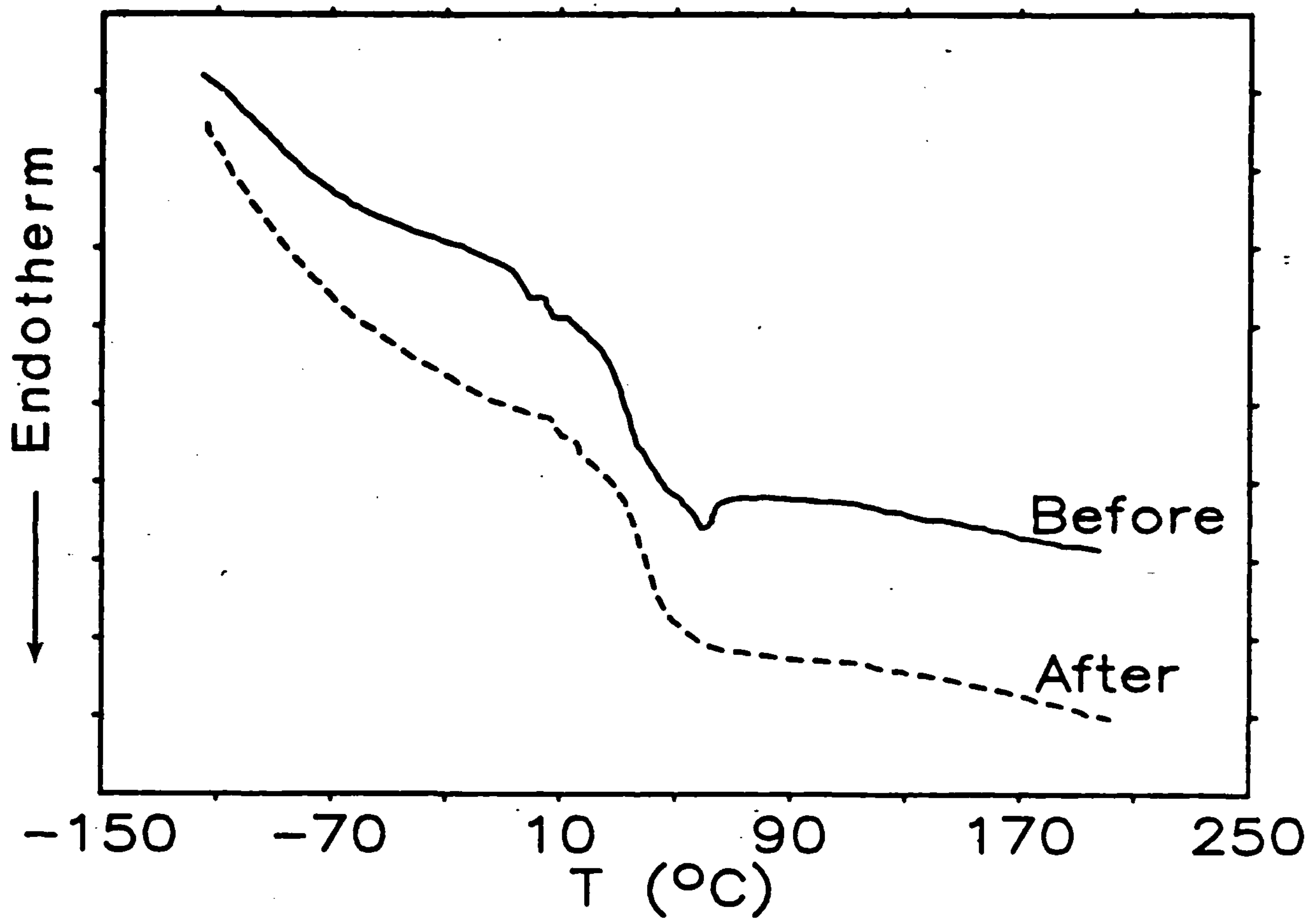


Figure 1

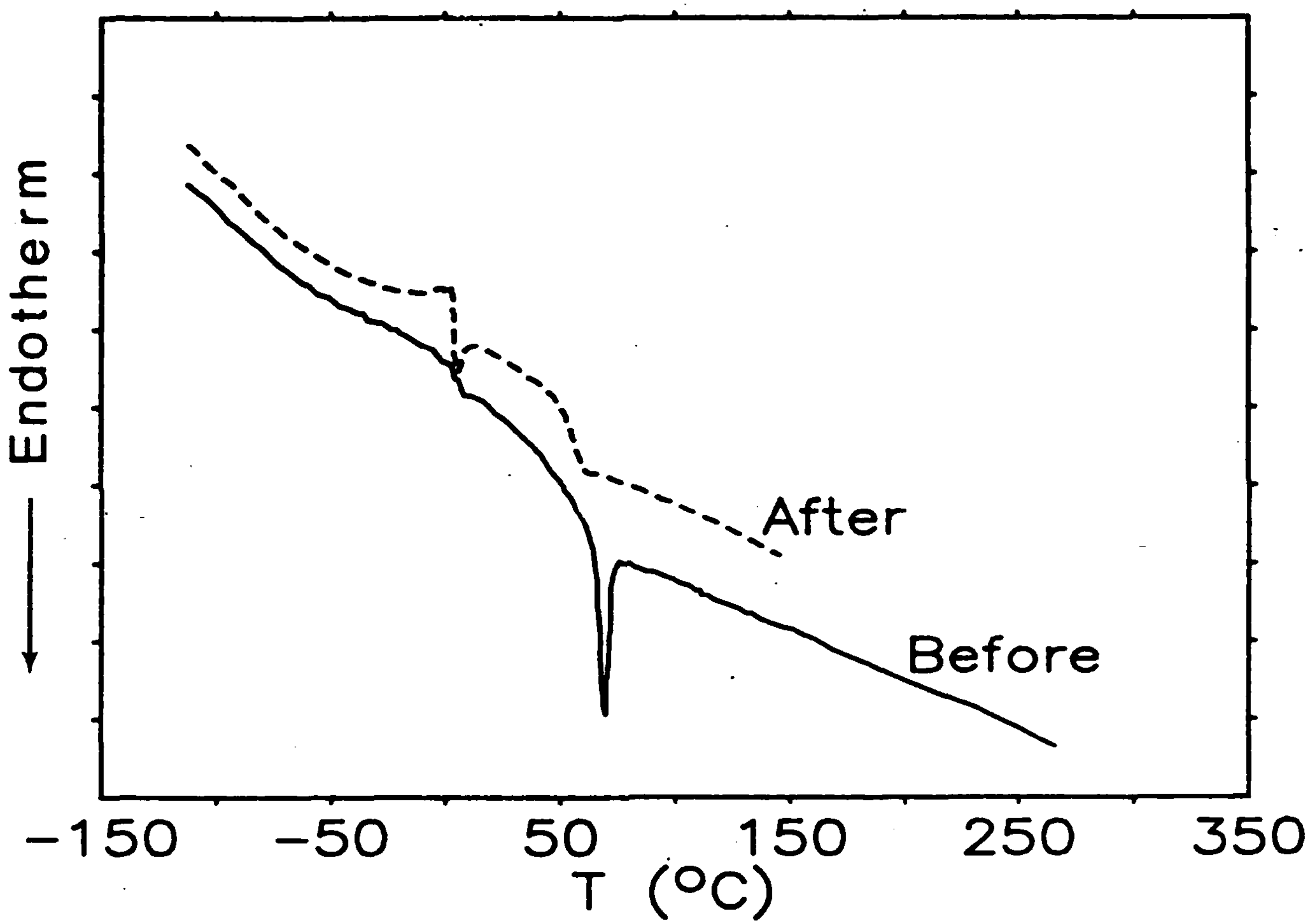


Figure 2

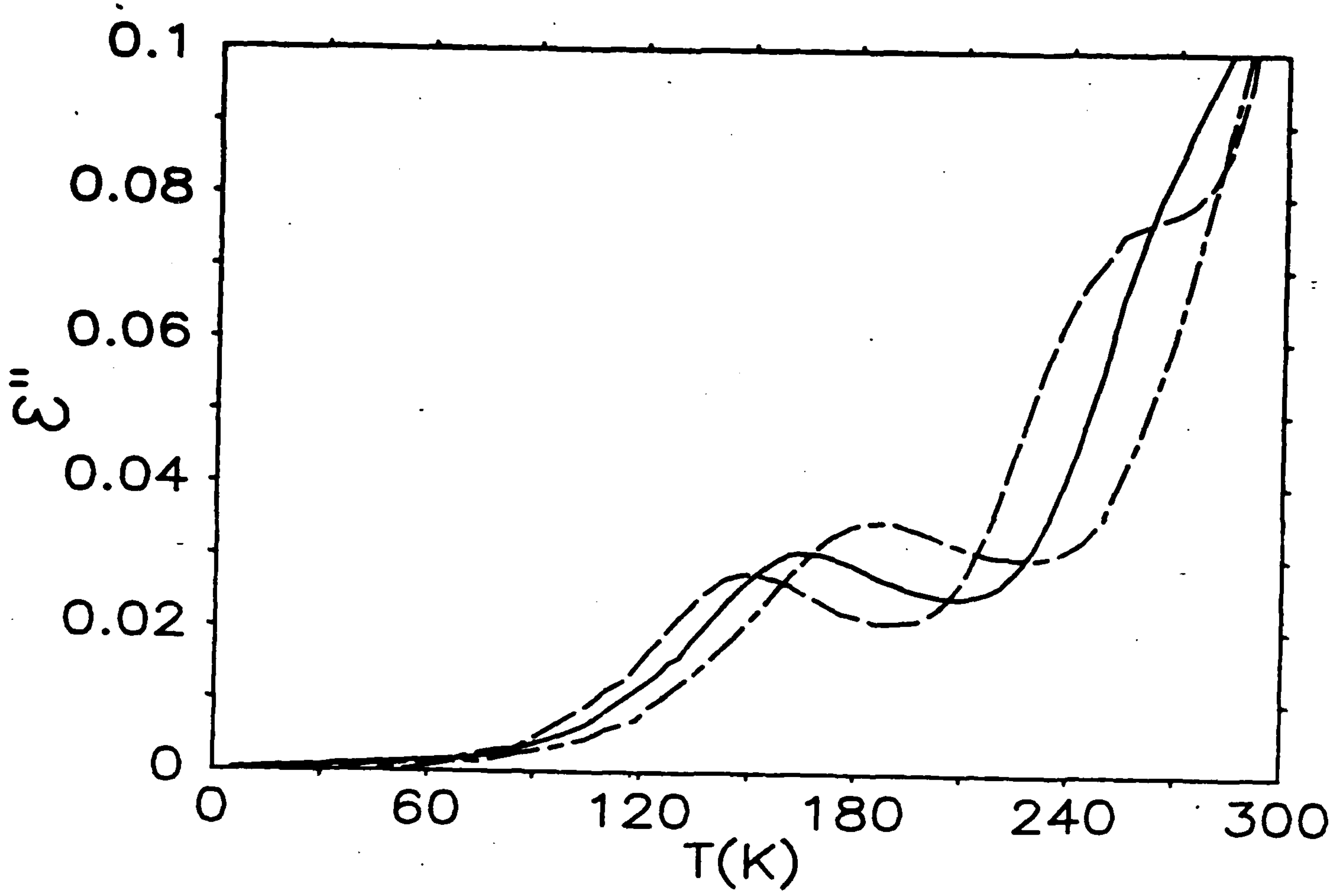


Figure 3

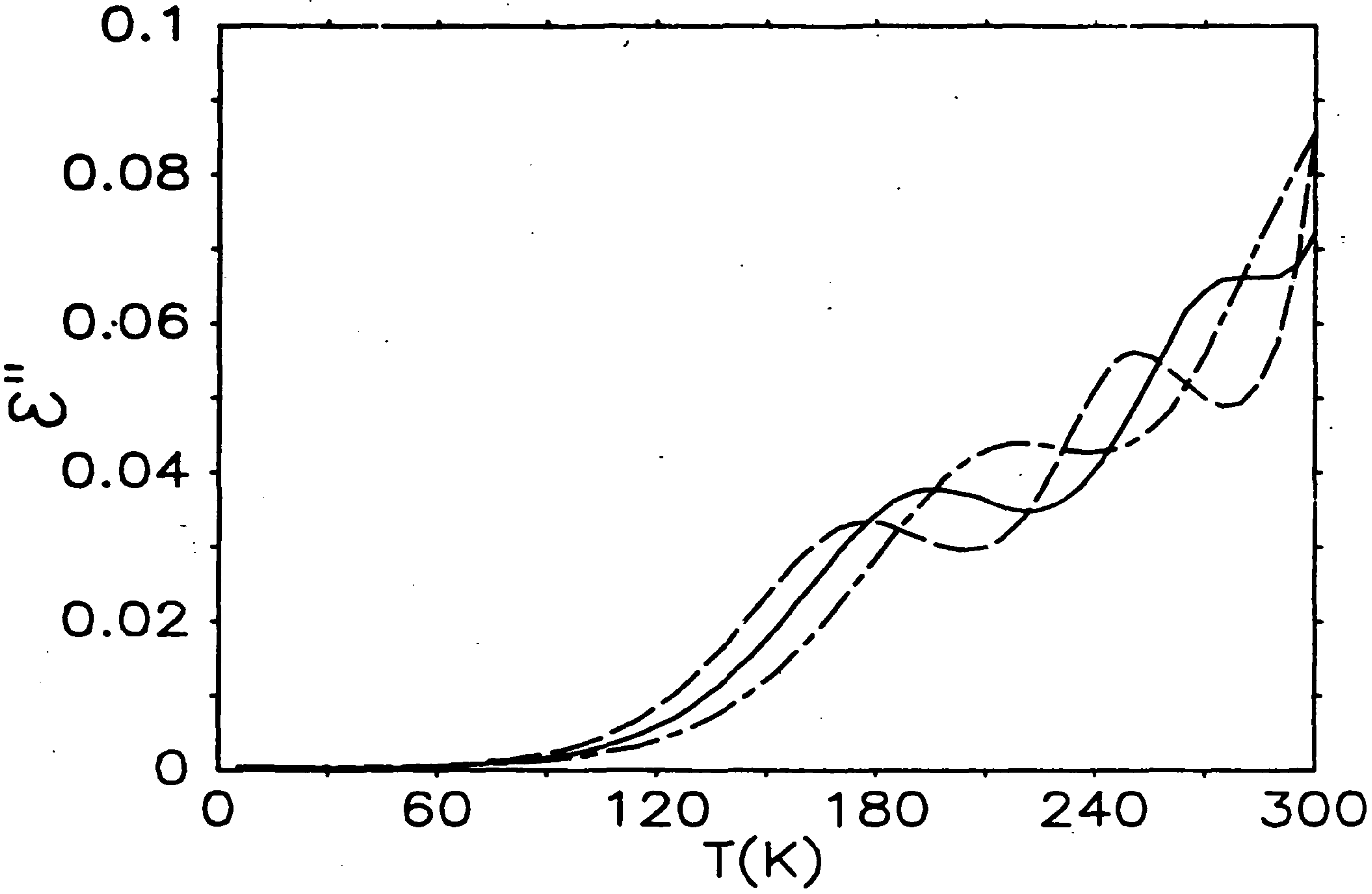


Figure 4

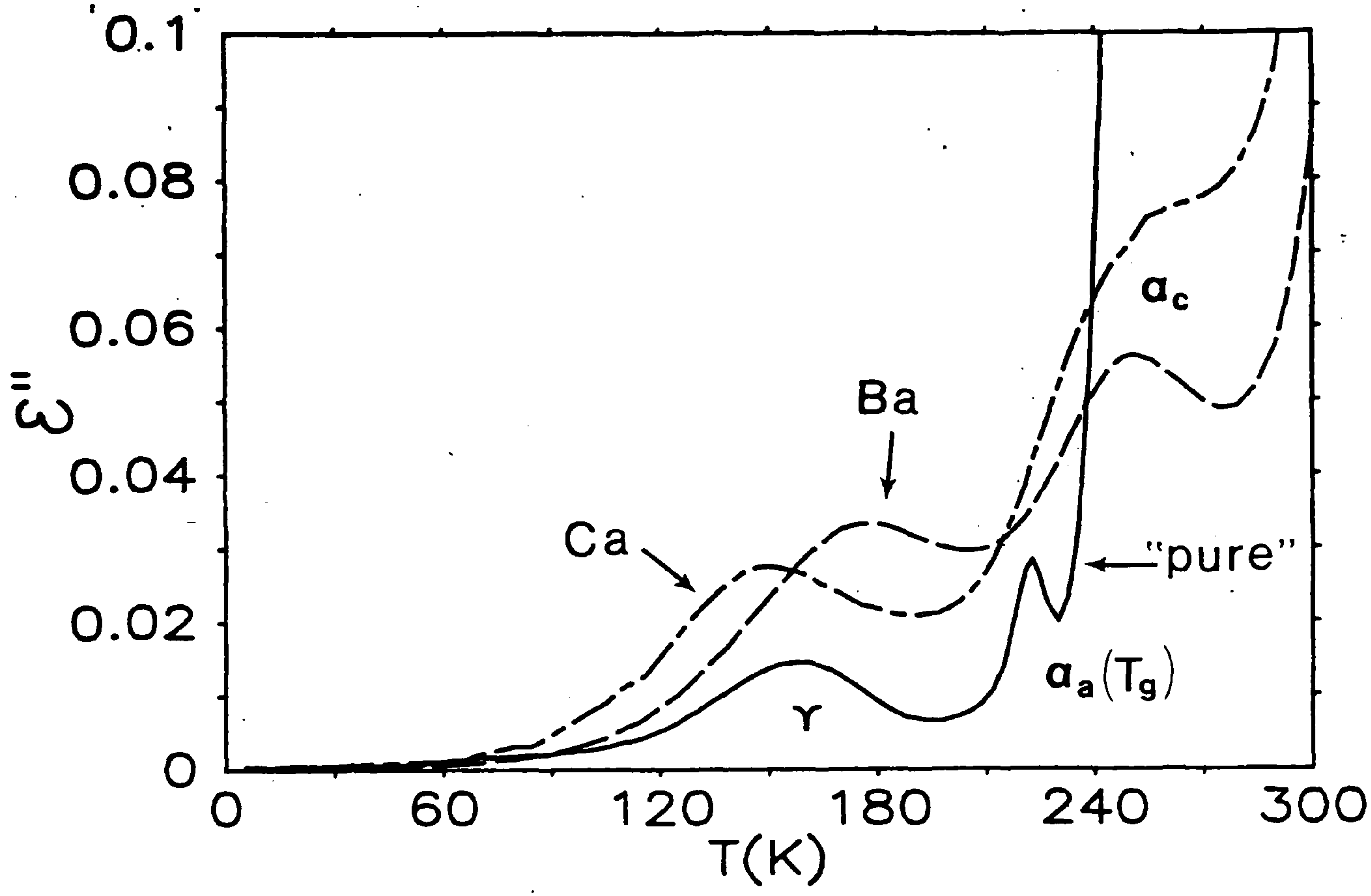


Figure 5

DL/413/83/01
359/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. M. Wrighton
Chemistry Department
Massachusetts Institute
of Technology
Cambridge, Massachusetts 02139

Dr. B. Stanley Pons
Department of Chemistry
University of Utah
Salt Lake City, Utah 84112

Donald E. Mains
Naval Weapons Support Center
Electrochemical Power Sources Division
Crane, Indiana 47522

S. Ruby
DOE (STOR)
M.S. 6B025 Forrestal Bldg.
Washington, D.C. 20595

Dr. A. J. Bard
Department of Chemistry
University of Texas
Austin, Texas 78712

Dr. Janet Osteryoung
Department of Chemistry
State University of New York
Buffalo, New York 14214

Dr. Donald W. Ernst
Naval Surface Weapons Center
Code R-33
White Oak Laboratory
Silver Spring, Maryland 20910

Mr. James R. Moden
Naval Underwater Systems Center
Code 3632
Newport, Rhode Island 02840

Dr. Bernard Spielvogel
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

Dr. William Ayers
ECD Inc.
P.O. Box 5357
North Branch, New Jersey 08876

Dr. M. M. Nicholson
Electronics Research Center
Rockwell International
3370 Miraloma Avenue
Anaheim, California

Dr. Michael J. Weaver
Department of Chemistry
Purdue University
West Lafayette, Indiana 47907

Dr. R. David Rauh
EIC Corporation
111 Chapel Street
Newton, Massachusetts 02158

Dr. Aaron Wold
Department of Chemistry
Brown University
Providence, Rhode Island 02192

Dr. Martin Fleischmann
Department of Chemistry
University of Southampton
Southampton S09 5NH ENGLAND

Dr. R. A. Osteryoung
Department of Chemistry
State University of New York
Buffalo, New York 14214

Dr. Denton Elliott
Air Force Office of Scientific
Research
Bolling AFB
Washington, D.C. 20332

Dr. R. Nowak
Naval Research Laboratory
Code 6130
Washington, D.C. 20375

Dr. D. F. Shriver
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Dr. Aaron Fletcher
Naval Weapons Center
Code 3852
China Lake, California 93555

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. David Aikens
Chemistry Department
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. A. P. B. Lever
Chemistry Department
York University
Downsview, Ontario M3J1P3

Dr. Stanislaw Szpak
Naval Ocean Systems Center
Code 6343, Bayside
San Diego, California 95152

Dr. Gregory Farrington
Department of Materials Science
and Engineering
University of Pennsylvania
Philadelphia, Pennsylvania 19104

M. L. Robertson
Manager, Electrochemical
and Power Sources Division
Naval Weapons Support Center
Crane, Indiana 47522

Dr. T. Marks
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Dr. Micha Tomkiewicz
Department of Physics
Brooklyn College
Brooklyn, New York 11210

Dr. Lesser Blum
Department of Physics
University of Puerto Rico
Rio Piedras, Puerto Rico 00931

Dr. Joseph Gordon, II
IBM Corporation
K33/281
5600 Cottle Road
San Jose, California 95193

Dr. D. H. Whitmore
Department of Materials Science
Northwestern University
Evanston, Illinois 60201

Dr. Alan Bewick
Department of Chemistry
The University of Southampton
Southampton, SO9 5NH ENGLAND

Dr. E. Anderson
NAVSEA-56Z33 NC #4
2541 Jefferson Davis Highway
Arlington, Virginia 20362

Dr. Bruce Dunn
Department of Engineering &
Applied Science
University of California
Los Angeles, California 90024

Dr. Elton Cairns
Energy & Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Dr. D. Cipris
Allied Corporation
P.O. Box 3000R
Morristown, New Jersey 07960

Dr. M. Philpott
IBM Corporation
5600 Cottle Road
San Jose, California 95193

Dr. Donald Sandstrom
Department of Physics
Washington State University
Pullman, Washington 99164

Dr. Carl Kannewurf
Department of Electrical Engineering
and Computer Science
Northwestern University
Evanston, Illinois 60201

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. Robert Somoano
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

Dr. Johann A. Joebstl
USA Mobility Equipment R&D Command
DRDME-EC
Fort Belvoir, Virginia 22060

Dr. Judith H. Ambrus
NASA Headquarters
M.S. RTS-6
Washington, D.C. 20546

Dr. Albert R. Landgrebe
U.S. Department of Energy
M.S. 6B025 Forrestal Building
Washington, D.C. 20595

Dr. J. J. Brophy
Department of Physics
University of Utah
Salt Lake City, Utah 84112

Dr. Charles Martin
Department of Chemistry
Texas A&M University
College Station, Texas 77843

Dr. H. Tachikawa
Department of Chemistry
Jackson State University
Jackson, Mississippi 39217

Dr. Theodore Beck
Electrochemical Technology Corp.
3935 Leary Way N.W.
Seattle, Washington 98107

Dr. Farrell Lytle
Boeing Engineering and
Construction Engineers
P.O. Box 3707
Seattle, Washington 98124

Dr. Robert Gotscholl
U.S. Department of Energy
MS G-226
Washington, D.C. 20545

Dr. Edward Fletcher
Department of Mechanical Engineering
University of Minnesota
Minneapolis, Minnesota 55455

~~Dr. John Fontanella~~
~~Department of Physics~~
~~U.S. Naval Academy~~
~~Annapolis, Maryland 21402~~

Dr. Martha Greenblatt
Department of Chemistry
Rutgers University
New Brunswick, New Jersey 08903

Dr. John Wasson
Syntheco, Inc.
Rte 6 - Industrial Pike Road
Gastonia, North Carolina 28052

Dr. Walter Roth
Department of Physics
State University of New York
Albany, New York 12222

Dr. Anthony Sammells
Eltron Research Inc.
710 E. Ogden Avenue #108
Naperville, Illinois 60540

Dr. W. M. Risen
Department of Chemistry
Brown University
Providence, Rhode Island 02192

Dr. C. A. Angell
Department of Chemistry
Purdue University
West Lafayette, Indiana 47907

Dr. Thomas Davis
Polymer Science and Standards
Division
National Bureau of Standards
Washington, D.C. 20234