CORRELATION OF ELECTRONIC CHARGE TRANSFER TRANSITIONS
AND ELECTROCHEMICAL. (U) YORK UNIV DOWNSVIEW (ONTARIO)
DEPT OF CHEMISTRY E S DODSWORTH ET AL. OCT 84 TR-33
UNCLASSIFIED N00014-78-C-0592
Correlation of Electronic Charge Transfer Transitions and Electrochemical Potentials. The Bipyrazine(Tetracarbonyl)Molybdenum(0) System in Various Solvents

BY
Elaine S. Dodsworth and A.B.P. Lever

Prepared for Publication in
Chemical Physics Letters

York University
Department of Chemistry
Downsview (Toronto)
Ontario M3J-1P3

Reproduction in whole or in part is permitted for any purpose of the United States Government.

This document has been approved for public release and sale; its distribution is unlimited.
**Correlation of Electronic Charge Transfer Transitions and Electrochemical Potentials. The Bipyrazine(Tetracarbonyl)Molybdenum(0) System in Various Solvents**

**Elaine S. Dodsworth and A.B.P. Lever***

**Department of Chemistry, York University**
4700 Keele St., Downsview, Ontario, M3J 1P3

**Office of Naval Research**
800 N. Quincy
Arlington, VA 22217

**Unclassified**

Using a free energy diagram, a relationship is drawn between an optical charge transfer energy and the electrochemical potentials of the donor and acceptor orbitals concerned. The charge transfer spectroscopy and electrochemical potentials of the title complex were studied in various solvents. A linear correlation, with negative slope, was observed between the difference in oxidation and reduction potentials and an MLCT transition. Using some additional solvent data, a number of useful parameters were derived in a fashion which would not be possible through consideration of either technique alone.
Correlation of Electronic Charge Transfer Transitions and Electrochemical Potentials. The Bipyrazine(Tetracarbonyl)-Molybdenum(0) System in Various Solvents

By Elaine S. Dodsworth and A.B.P. Lever
Dept. of Chemistry, York University, Downsview(Toronto), Ontario, Canada, M3J 1P3.

Abstract

Using a free energy diagram, a relationship is drawn between an optical charge transfer energy and the electrochemical potentials of the donor and acceptor orbitals concerned. The charge transfer spectroscopy and electrochemical potentials of the title complex were studied in various solvents. A linear correlation, with negative slope, was observed between the difference in oxidation and reduction potentials and an MLCT transition. Using some additional solvent data, a number of useful parameters were derived in a fashion which would not be possible through consideration of either technique alone.

An electronic charge transfer transition involves excitation from a donor orbital in the ground state of a molecule, to an acceptor orbital in a Franck-Condon (non-equilibrium) excited state of the molecule. In this paper we refer specifically to an MLCT transition, from an orbital, \( \Psi_M \), mainly on the metal, to an orbital, \( \Psi_L \), primarily on the ligand. However the treatment is quite general.

An electrochemical study may, in appropriate cases, define the redox potentials of orbitals related to those above. Thus we may
observe the oxidation potential of $\psi_h$ in the ground state of the complex $ML_n$, and the reduction potential for adding an electron to $\psi_L$ to form the ground state of the reduced species $ML_n^-$. 

Previous authors [1-5] have demonstrated qualitative relationships between optical charge transfer energies and electrochemical potentials but now we seek a more quantitative understanding in which quantities not derivable from either electronic spectroscopy or electrochemistry alone, can be obtained by a combined analysis.

In view of the solvation contributions to the parameters obtained with each technique, a combined analysis is best approached within the framework of the collection and comparison of data in a range of solvents. The analysis which follows is based upon theories developed by Born [6], Onsager [7], Kirkwood [8], Lippert [9], Marcus [10] and Meyer [11].

Use of a free energy cycle (Fig.1) permits one to relate the various thermodynamic quantities (as defined in the legend to Fig.1), measurable in the two experimental regimes. Thus the following equalities may be written:-

$$E_{op} = \Delta E_s + \chi_i + \chi_0$$

(1)

$$\Delta E_s = \Delta E_g + \Delta(sol)$$

(2)

$$\Delta E_g = nF\Delta \varepsilon(\text{redox}) + \Delta \Delta G_s + Q$$

$$= (nF\Delta \varepsilon'(\text{redox}) + \chi) + \Delta \Delta G_s + Q \text{ (see text below)}$$

(3)
and hence:

$$E_{op} = \left[ \chi_i + nF \Delta H(\text{redox}) + \Delta G_s + Q \right] + \chi_0 + \Delta(\text{sol})$$

(4)

where $\chi_0 + \Delta(\text{sol})$ is the total change in solvation free energy as earlier defined in [10b] eqn.(13), and [9] eqn.B2a, and $\chi_i$ and $\chi_0$ are the inner sphere (vibrational) and outer-sphere (solvent, but also vibrational in nature) contributions to the reorganisation energy of the transition, respectively. Note that as a consequence of the Franck-Condon nature of the excited state, the transition energy $E_{op}$ is a free energy in that the entropies of the ground and non-equilibrated excited state are the same [10b].

Equation (4), in which the square bracketed function is solvent independent for a given molecule, provides the important correlation between the two techniques.

The complex $\text{Mo(CO)}_4\text{bps}$ ($\text{bps} = \text{bipyrazine}$) [12] displays a strong band, inter alia, attributed to $d(\text{Mo}(0)) \rightarrow \pi^*(\text{bps})$ MLCT, whose energy, $E_{op}$, varies from about 16,000 to 20,000 cm$^{-1}$ depending upon the solvent environment and shifting to higher energy with increasing solvent polarity, (Table 1) (cf the solvatochromism of the bipyridine analog [13]). Electrochemical data for a range of solvents are also shown in Table 1.

The reduction potential for the electrochemically reversible $\text{Mo(CO)}_4\text{bps}/\text{Mo(CO)}_4\text{bps}^-$ couple involves addition of an electron to $\Phi_L (\pi^* \text{ bps})$ forming the radical bps$^-$ bound to Mo(0). This couple shifts to more positive potentials with increasing polarity of the solvent, as the ground state radical anion becomes more solvent
stabilised.

Oxidation occurs at the Mn(0) d manifold but is electrochemically irreversible, due to a following chemical reaction (EC mechanism) [15,16]. However the slow step of the following reaction appears to be Mn-CO bond breaking which is solvent independent. Thus the true thermodynamic potential will be more positive than recorded in Table 1 by a solvent independent quantity, say x mV (probably 100 < x < 300). Thus ΔE(redox) in (4) is replaced by ΔE'(redox) + x, where ΔE'(redox) is the experimental difference between the oxidation and reduction potentials.

A plot of E_op against ΔE'(redox) is linear with negative slope (correlation coefficient 0.98):-

\[ E_{op} = -1.04 \Delta E'(\text{redox}) + 33,950 \text{ (in cm}^{-1}\text{)} \]  

(5)

This is an unexpected result appearing to contradict intuition in that as the potential difference between donor and acceptor orbital decreases, the optical transition energy increases. Such an inverse correlation has not been previously reported. An understanding of this phenomenon develops from further analysis below.

The expression (6) [8] allows one to approximate the solvation free energy of a species as a power series:

\[ \Delta G_s = 0.5 \sum_{n=0}^{\infty} \left( \frac{(n+1)Q_n}{b^{2n+1}} \right) \left[ \frac{1-D_s}{((n+1)D_s + n)} \right] \]  

(6)

where terms higher than n = 1 are ignored and the reader is
referred to the earlier literature [6-11] for detailed discussion of the conditions under which this expression is useful. $D_s$ is the static dielectric constant of the solvent, $b$ is the radius of the solute, $Q_0 = z^2e^2$, and $Q_1 = \mu^2$, where $\mu$ is the dipole moment of the solute species. The term in $n = 0$ disappears for uncharged species. The difference in solvation free energies of the uncharged and thermally equilibrated ground and excited states, $\Delta\text{sol}$, may be written using (6) as:

$$\Delta\text{sol} = \Delta G_s(e) - \Delta G_s(g) = ((\mu_e^2 - \mu_g^2)/b^3)[(1-D_s)/(2D_s+1)]$$

(7)

Following earlier authors [8-11], the Franck-Condon destabilisation of the excited state, due to solvent interactions, may be written:

$$\chi_0 = ((\mu_e - \mu_g)^2/b^3)[(1-D_{op})/(2D_{op}+1) - (1-D_s)/(2D_s+1)]$$

(8)

where in (7,8) the ground and excited state dipole moments are appropriately discriminated, and $D_{op}$ is the optical dielectric constant of the solvent (square of the refractive index). The total solvent dependence excluding non-polar contributions (very small [10b]), (eqn.(4)) is

$$\Delta \equiv \Delta\text{sol} + \chi_0$$

Summing (7) and (8) yields (9) (after evaluating the vector products) [9,11]:

$$\Delta \equiv (\mu_e^2 + \mu_g^2 - 2\mu_e\mu_g\cos\theta)/b^3)[(1-D_{op})/(2D_{op}+1)]$$

$$+ 2\mu_g(\mu_e\cos\theta - \mu_g)/b^3)[(1-D_s)/(2D_s+1)]$$

(9)

The angle $\theta$ is that between the ground and excited state
dipoles. The ground state dipole moment lies along the $C_2$ axis with the negative end pointing towards the CO groups.

Equation (4) can now be recast in the general form:

$$E_{op} = \chi_i + \Delta E_g + f(1-D_{op})/(2D_{op}+1) + f'(1-D_s)/(2D_s+1)$$

(10)

where $f$ and $f'$ group the factors shown in eqn.(9).

In a forthcoming paper [15] we develop this analysis with 23 solvents. Here we shall restrict ourselves to considering six solvents of low polarity and low dielectric constant which might be expected to obey the dielectric continuum model. The optical data thereof (Table 1) obey (10) well according to (in cm$^{-1}$):

$$E_{op} = 9500((1-D_{op})/(2D_{op}+1)) - 7600((1-D_s)/(2D_s+1)) + 16,800$$

(11)

with a correlation coefficient of 0.988 and a standard deviation of 65 (the lower set of six solvents shown in Table 1 were used), and where the constant term, 16,800 cm$^{-1}$ is associated with $\chi_i + \Delta E_g$. However the data yield a family of solutions which do not differ greatly in their correlation coefficients or standard deviations. Indeed the solution $f = 0$, $f' = -7110$, and $\chi_i + \Delta E_g = 15,110$ cm$^{-1}$ is not unreasonable (correlation coefficient 0.97, standard deviation 169). This latter solution is, however, inconsistent with the expressions in (9). The solution in (11) is statistically the best, but does not differ significantly from many other solutions in which $f$ lies between zero and 9500 cm$^{-1}$. However $f'$ is generally found in the range $-(7000 - 7700)$ cm$^{-1}$ and the constant ranges from about 15,000 - 17,000 cm$^{-1}$. At this stage
of study we note that the approach seems justified but that higher quality and more extensive data are necessary.

The negative value for $f'$ requires, considering equations (8-11), that, in this system, the dipole moment changes direction by $180^\circ$ in the excited state relative to the ground state [2,15]. This provides an understanding of the Franck-Condon destabilisation of the excited state by polar solvents, and hence of the negative correlation shown in (5).

For the purpose of indicating how these data may be utilised, we choose a median value of the constant of $16,000 \text{ cm}^{-1}$.

Note that in the gas phase, $\Delta G^\circ = 0$, therefore $X_i + nF\Delta E'(\text{redox}) + x + Q = 16,000 \text{ cm}^{-1}$. Further, use of eqn. (5) provides the value for $nF\Delta E'(\text{redox})$ in the gas phase by insertion of $E_{op} = 16,000 \text{ cm}^{-1}$. Knowing $\Delta E'(\text{redox})$ allows derivation of $X_i + x + Q = -1260 \text{ cm}^{-1}$. This then leads to the evaluation of $\Delta G^\circ$ (eqn.3). Use of eqn (4) leads to evaluation of $\Delta(\text{sol}) + X_0$.

These data are also collected in Table 1.

The sum $(X_i + x)$ is necessarily positive but $Q$, using an appropriate free energy cycle, is estimated to be near $-0.5V$ [15]. The 'gas phase' optical energy is close to that observed in pentane, as might be anticipated. The procedure provides an interesting set of parameters whose values seems eminently reasonable. Further development on this and related systems should provide the impetus to link the study of electrochemistry and optical spectroscopy and to seek evaluation of other useful parameters, such as the self-exchange energy, which may be derivable from a free energy cycle involving $Q$. The merits and boundary conditions inherent in this analysis will be discussed in
more detail in a future publication [15]. We also currently seek emission data which should further define some of the parameters derived.

Acknowledgments: The authors are indebted to the Natural Sciences and Engineering Research Council (Ottawa) and the Office of Naval Research (Washington) for financial support. We also gratefully acknowledge useful discussions with Profs. T.J. Meyer and I.M. Walker.


15. E. S. Dodsworth and A. B. P. Lever, to be submitted.

Table 1

<table>
<thead>
<tr>
<th>Solvent</th>
<th>E(Mo(I))</th>
<th>E(bpz)</th>
<th>ΔE' (redox)</th>
<th>E₀ (op)</th>
<th>X₀⁺</th>
<th>ΔΔGₜ (sol)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>eV</td>
<td>eV</td>
<td>eV</td>
<td>cm⁻¹</td>
<td>cm⁻¹</td>
<td>cm⁻¹</td>
</tr>
<tr>
<td>DMF</td>
<td>0.26</td>
<td>-1.42</td>
<td>1.68 (13,550)</td>
<td>19,650</td>
<td>3650</td>
<td>3710</td>
</tr>
<tr>
<td>PC</td>
<td>0.32</td>
<td>-1.41</td>
<td>1.73 (14,000)</td>
<td>19,550</td>
<td>3550</td>
<td>3260</td>
</tr>
<tr>
<td>MeCN</td>
<td>0.28</td>
<td>-1.45</td>
<td>1.73 (14,000)</td>
<td>19,450</td>
<td>3450</td>
<td>3260</td>
</tr>
<tr>
<td>PY</td>
<td>0.26</td>
<td>-1.52</td>
<td>1.78 (14,350)</td>
<td>18,900</td>
<td>2900</td>
<td>2910</td>
</tr>
<tr>
<td>THF</td>
<td>0.30</td>
<td>-1.52</td>
<td>1.82 (14,700)</td>
<td>18,650</td>
<td>2650</td>
<td>2560</td>
</tr>
<tr>
<td>DCE</td>
<td>0.34</td>
<td>-1.53</td>
<td>1.87 (15,100)</td>
<td>18,150</td>
<td>2150</td>
<td>2160</td>
</tr>
<tr>
<td>DCM</td>
<td>-</td>
<td>-</td>
<td>1.90° (15,350)</td>
<td>17,990</td>
<td>1990</td>
<td>1910</td>
</tr>
<tr>
<td>Et₂O</td>
<td>1.93°</td>
<td>(15,530)</td>
<td>17,790</td>
<td>1790</td>
<td>1730</td>
<td></td>
</tr>
<tr>
<td>CHCl₃</td>
<td>1.96°</td>
<td>(15,950)</td>
<td>17,360</td>
<td>1360</td>
<td>1310</td>
<td></td>
</tr>
<tr>
<td>TCM</td>
<td>2.07°</td>
<td>(16,670)</td>
<td>16,610</td>
<td>610</td>
<td>590</td>
<td></td>
</tr>
<tr>
<td>Pent</td>
<td>2.09°</td>
<td>(16,870)</td>
<td>16,400</td>
<td>400</td>
<td>390</td>
<td></td>
</tr>
<tr>
<td>'Gas'</td>
<td>2.14°</td>
<td>(17,260)</td>
<td>16,000</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

a) All electrochemical potentials referenced against ferrocene as internal referant (Fc⁺/Fc is at 0.16 eV vs. sce) [14]. Potentials were recorded on Pt electrodes using cyclic voltammetry at scan rates of 100, 50 and 20 mV/s. Confirmatory data were obtained using differential pulse polarography. Data are averages of several experiments.
b) The oxidation process is electrochemically irreversible. Eₚ - Eₚ/2 is comparable to that of the ferrocene couple under the same conditions. Value quoted is 1/2(Eₚ + Eₚ/2).
c) Calculated from eqn.(5) in text. NB ΔE' = 16000 cm⁻¹; X₀⁺ + X + Q = -1260 cm⁻¹.
DMF = dimethylformamide; PC = propylene carbonate; PY = pyridine; THF = tetrahydrofuran; DCE = 1,2-dichloroethane; DCM = dichloromethane; TCM = tetrachloromethane; Pent = pentane. 'Gas' is extrapolation using eqn.(11).
Fig. 1 Free energy diagram relating spectroscopic and electrochemical quantities.

(ML) is the neutral species, and (ML*), (ML+) and (ML-) are the equilibrated excited, mono-positive and mono-negative species respectively. Similarly \( \Delta G_s \), \( \Delta G_s^* \), \( \Delta G_s^+ \) and \( \Delta G_s^- \) are the solvation free energies for these respective species being defined as the reversible work to transfer these solutes from the gas phase to a solvent. \( \Delta E_{\text{redox}} \) is defined as the oxidation potential minus the reduction potential of the neutral species.

\( \Delta E_g \) is the gas phase excitation energy to the equilibrated excited state. \( \Delta E_s \) is the solvent phase excitation energy to the equilibrated excited state. The quantity \( Q \) is the resonance energy involved in transferring an electron from (ML-) to (ML+) yielding (ML) + (ML*). Note that in the text \( \Delta G_s = 2AG_s - \Delta G_s^+ - \Delta G_s^- \) and \( \Delta (\text{sol}) = \Delta G_s^* - \Delta \).
<table>
<thead>
<tr>
<th>No. Copies</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office of Naval Research 2</td>
<td>Naval Ocean Systems Center 1 Attn: Technical Library Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232</td>
</tr>
<tr>
<td>Attn: Code 413</td>
<td>Naval Weapons Center 1 Attn: Dr. A. B. Amster Chemistry Division China Lake, California 93555</td>
</tr>
<tr>
<td>Attn: Code 413</td>
<td>Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380</td>
</tr>
<tr>
<td>Attn: Technical Library San Diego, California 92152</td>
<td>Naval Civil Engineering Laboratory 1 Attn: Dr. R. W. Drisko Port Hueneme, California 93401</td>
</tr>
<tr>
<td>Commander, Naval Air Systems Command 1 Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360</td>
<td>U.S. Army Research Office 1 Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709</td>
</tr>
<tr>
<td>Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360</td>
<td>Mr. Vincent Schaper DTNSRDC Code 2830 Annapolis, Maryland 21402</td>
</tr>
<tr>
<td>Superintendent 1</td>
<td>Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112</td>
</tr>
<tr>
<td>Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375</td>
<td>Mr. A. M. Anzalone Administrative Librarian PLASTEC/ARRADCOM Bldg 3401 Dover, New Jersey 07801</td>
</tr>
<tr>
<td>Defense Technical Information Center 12</td>
<td>Building 5, Cameron Station Alexandria, Virginia 22314</td>
</tr>
<tr>
<td>DTNSRDC 1</td>
<td>Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112</td>
</tr>
<tr>
<td>Attn: Dr. G. Bosmajian Applied Chemistry Division Annapolis, Maryland 21401</td>
<td>Mr. A. M. Anzalone Administrative Librarian PLASTEC/ARRADCOM Bldg 3401 Dover, New Jersey 07801</td>
</tr>
</tbody>
</table>
DL/413/83/01
359/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 359

Dr. Paul Delahay
Department of Chemistry
New York University
New York, New York 10003

Dr. P. J. Hendra
Department of Chemistry
University of Southampton
Southampton SO9 5NH
United Kingdom

Dr. T. Katan
Lockheed Missiles and Space Co., Inc.
P.O. Box 504
Sunnyvale, California 94088

Dr. D. N. Bennion
Department of Chemical Engineering
Brigham Young University
Provo, Utah 84602

Dr. R. A. Marcus
Department of Chemistry
California Institute of Technology
Pasadena, California 91125

Mr. Joseph McCartney
Code 7121
Naval Ocean Systems Center
San Diego, California 92152

Dr. J. J. Auborn
Bell Laboratories
Murray Hill, New Jersey 07974

Dr. Joseph Singer, Code 302-1
NASA-Lewis
21000 Brookpark Road
Cleveland, Ohio 44135

Dr. P. P. Schmidt
Department of Chemistry
Oakland University
Rochester, Michigan 48063

Dr. H. Richtol
Chemistry Department
Rensselaer Polytechnic Institute
Troy, New York 12181

Dr. E. Yeager
Department of Chemistry
Case Western Reserve University
Cleveland, Ohio 44106

Dr. C. E. Mueller
The Electrochemistry Branch
Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, Maryland 20910

Dr. Sam Perone
Chemistry & Materials Science Department
Lawrence Livermore National Lab.
Livermore, California 94550

Dr. Royce W. Murray
Department of Chemistry
University of North Carolina
Chapel Hill, North Carolina 27514

Dr. G. Goodman
Johnson Controls
5757 North Green Bay Avenue
Milwaukee, Wisconsin 53201

Dr. B. Brummer
EIC Incorporated
111 Chapel Street
Newton, Massachusetts 02158

Dr. Adam Heller
Bell Laboratories
Murray Hill, New Jersey 07974

Electrochimica Corporation
Attn: Technical Library
2485 Charleston Road
Mountain View, California 94040

Library
Duracell, Inc.
Burlington, Massachusetts 01803

Dr. A. B. Ellis
Chemistry Department
University of Wisconsin
Madison, Wisconsin 53706
TECHNICAL REPORT DISTRIBUTION LIST, 359

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

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

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

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

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

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

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

S. Ruby
DOE (STOR)
M.S. 68025 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. Martin Fleischmann
Department of Chemistry
University of Southampton
Southampton S09 5NH ENGLAND

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

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

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

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

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

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

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

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

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

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, S09 5NH ENGLAND

Dr. E. Anderson
NAVSEA-56233 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

<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Robert Somoano</td>
<td>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103</td>
</tr>
<tr>
<td>Dr. Johann A. Joebstl</td>
<td>USA Mobility Equipment R&amp;D Command, Fort Belvoir, Virginia 22060</td>
</tr>
<tr>
<td>Dr. Judith H. Ambrus</td>
<td>NASA Headquarters, M.S. RTS-6, Washington, D.C. 20546</td>
</tr>
<tr>
<td>Dr. Albert R. Landgrebe</td>
<td>U.S. Department of Energy, M.S. 68025 Forrestal Building, Washington, D.C. 20595</td>
</tr>
<tr>
<td>Dr. J. J. Brophy</td>
<td>Department of Physics, University of Utah, Salt Lake City, Utah 84112</td>
</tr>
<tr>
<td>Dr. Charles Martin</td>
<td>Department of Chemistry, Texas A&amp;M University, College Station, Texas 77843</td>
</tr>
<tr>
<td>Dr. H. Tachikawa</td>
<td>Department of Chemistry, Jackson State University, Jackson, Mississippi 39217</td>
</tr>
<tr>
<td>Dr. Theodore Beck</td>
<td>Electrochemical Technology Corp., 3935 Leary Way N.W., Seattle, Washington 98107</td>
</tr>
<tr>
<td>Dr. Farrell Lyle</td>
<td>Boeing Engineering and Construction Engineers, P.O. Box 3707, Seattle, Washington 98124</td>
</tr>
<tr>
<td>Dr. Edward Fletcher</td>
<td>Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minnesota 55455</td>
</tr>
<tr>
<td>Dr. John Fontanella</td>
<td>Department of Physics, U.S. Naval Academy, Annapolis, Maryland 21402</td>
</tr>
<tr>
<td>Dr. Martha Greenblatt</td>
<td>Department of Chemistry, Rutgers University, New Brunswick, New Jersey 08903</td>
</tr>
<tr>
<td>Dr. John Wasson</td>
<td>Syntheco, Inc., Rte 6 - Industrial Pike Road, Gastonia, North Carolina 28052</td>
</tr>
<tr>
<td>Dr. Walter Roth</td>
<td>Department of Physics, State University of New York, Albany, New York 12222</td>
</tr>
<tr>
<td>Dr. Anthony Sammells</td>
<td>Eltron Research Inc., 710 E. Ogden Avenue #108, Naperville, Illinois 60540</td>
</tr>
<tr>
<td>Dr. W. M. Risen</td>
<td>Department of Chemistry, Brown University, Providence, Rhode Island 02192</td>
</tr>
<tr>
<td>Dr. C. A. Angell</td>
<td>Department of Chemistry, Purdue University, West Lafayette, Indiana 47907</td>
</tr>
<tr>
<td>Dr. Thomas Davis</td>
<td>Polymer Science and Standards Division, National Bureau of Standards, Washington, D.C. 20234</td>
</tr>
</tbody>
</table>