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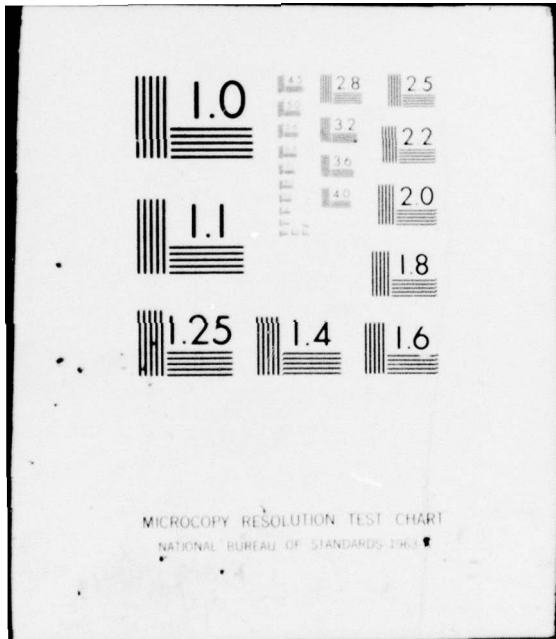
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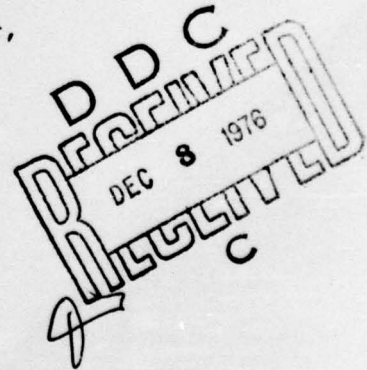
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THE 10th INTERNATIONAL POWER SOURCES SYMPOSIUM

21 October 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A summary is given of the 10th International Power Sources Symposium at which 48 papers were presented. Emphasis in the review is placed upon secondary batteries with high energy density, i.e., those most suitable for electrically powered vehicles. An introductory discussion of the principles of batteries and measures of performance is also included.		

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THE 10th INTERNATIONAL
POWER SOURCES SYMPOSIUM

by

Dr. W. G. Soper

Introduction

Environmental pollution and the prospect of dwindling supplies of low-cost fuels have intensified interest in electrical storage systems. In power distribution networks, more efficient means for storing electrical energy will permit the satisfaction of peak demands without investment in larger generating plants. Also, with such storage capability, plants can be operated continuously at peak efficiency without wasteful low-load periods.

Electrically powered vehicles will undoubtedly play an increasing role in transportation as alternative energy sources are developed and as pollution controls become more stringent. For these vehicles, higher energy batteries are vital if range and payload are to be at all comparable with the hydrocarbon-powered vehicles of today.

This was the background for the 10th International Power Sources Symposium which was held at Brighton, England 13-16 September 1976. Devoted entirely to batteries and fuel cells, the Symposium featured 48 papers by an international group of researchers. Over half the papers were American or British in origin.

The range of topics covered in the Symposium was very broad, and for this reason it seems appropriate to precede a review of selected papers with a brief discussion of batteries in general. In this way, a framework can be established within which the subject matter of the conference can be discussed. Also, certain definitions and concepts which occurred repeatedly in the papers can be explained.

Batteries in General


To the layman, "battery" may denote one of a few special chemical systems which can store electrical energy for later release into a motor, lamp, or other electrical device. This impression is reasonable when one considers the relatively few types of batteries that have achieved a wide market; the "dry cell" and the lead storage battery dominate the field.

A closer examination of the matter reveals, however, that a battery is basically a mechanical configuration which splits a chemical reaction into two parts. The separation is such that, in order for the reaction to proceed, electrical current must flow externally from one post or electrode of the battery to the other. This external flow is accompanied by an internal flow of ions through the electrolyte.

Such a transfer of charge occurs in all chemical reactions; the battery just forces the flow to follow an external path where it can do useful work, rather than be dissipated as heat. From this point of view it is clear that the topic of batteries encompasses the gamut of chemical reactions. Organic, inorganic, solid, liquid, and gaseous--all types and states of matter have the potential to provide useful energy storage systems.

Chemical Potential

While almost any chemical reaction can be utilized in a battery, high energy output requires a large difference in chemical potential for the two "half-reactions" which take place at the electrodes. A listing of the many reactions which can be paired to form a battery would be impracticable here, but the principle can be illustrated by the electrochemical series for some of the more common elements, as follows:

increasing potential


F, O, Cl, Ag, Hg, Cu, H, Pb, Mo, Ni, Cd, Fe, Zn, Ti, Al, Na, K, Li

The elements have been listed in order of increasing potential, and the energy content of a battery formed by any pair or "couple" is proportional to the difference in potentials. For example, the potentials of sodium and chlorine are +2.714 and -1.358 V, respectively, and that couple should theoretically produce 4.072 V. The theoretical energy output of such a cell is 1,870 watt-hours per kilogram (Wh/kg).

It is clear from this that maximum energy is realized by selecting elements from the extremes of the electrochemical array, with the couple fluorine-lithium representing the ultimate. Of course, many other factors besides energy influence the selection of reactions for batteries. Progress in batteries is largely the result of moving toward the extremes of the electrochemical scale, at the same time satisfying the practical requirements of cost, safety, and longevity.

Two Classes of Batteries

Batteries are conveniently divided into two classes: primary and secondary. In primary cells, the reaction proceeds only once, and the cell is not recharged. In secondary cells, the reaction must be highly reversible so that hundreds or thousands of charge-discharge cycles can be performed without loss of performance. The requirement of reversibility significantly limits the reactions suitable for secondary batteries. Unfortunately, the more energetic the constituents, the less amenable to repeated cycling a cell is likely to be. However, chemical and mechanical schemes to cope with this perversity constitute an area of active research.

Measures of Performance

Performance of batteries is expressed in terms of several quantities. The fraction of stored charge which can be withdrawn defines the "coulombic efficiency," a high value of which is a necessary but not sufficient condition for good practical battery performance. Another measure of performance is the "energy density," or energy recovered per unit mass of battery. This quantity is related directly to the maximum range of a vehicle powered by a battery of fixed weight, and it is a parameter of primary importance. (For volume-limited applications, energy per unit battery volume is the appropriate form.) "Energy density efficiency" will be defined as the ratio of energy density in the real battery to the theoretical energy density of the reaction, the latter being based on the mass of reactants alone. Still another measure of performance is the "power density," the maximum power output per unit mass. This is related to the maximum speed attainable by a vehicle with a battery of fixed weight.

To define the magnitude of the challenge facing battery designers, it is pointed out that the energy density of gasoline is 12,900 Wh/kg. This is about three orders of magnitude above the storage capacity of present off-the-shelf batteries, and almost an order of magnitude above the maximum theoretical output of the highly energetic Na-Cl couple. The disparity is relieved slightly by the fact that petroleum fuels in conventional vehicles are burned to produce heat, which is in turn converted to mechanical power by heat engines of low efficiency (typically 25%), while electrical power from a battery can be converted to mechanical power by an electric motor with an efficiency of perhaps 75%.

Discussion of Selected Papers

No attempt will be made to discuss all the papers presented at the Symposium. Instead, the most significant papers (from the point of view of the writer) will be covered under several general headings. The coverage will emphasize secondary cells as being most germane to future energy storage requirements. (See Appendix for complete listing of papers presented. Paper number is indicated in the following discussion; however, the complete Proceedings will be published in the near future by the International Power Sources Symposium Committee, P.O. Box 17, Leatherhead, Surrey, England.)

Updating Older Cells

The Symposium began with a session on the familiar lead-sulfuric acid storage battery. Two papers^{1,2} dealt with the potential distribution in the current-collecting grids and presented means for optimizing conductor dimensions to minimize resistance losses. Gwent College, Wales, has conducted a very interesting study⁴ of battery efficiency under pulsed loading typical of chopper-controlled vehicles. Surprisingly, it was found that the efficiency is at least as high as would

be expected for steady load at the average current flow. This result is attributed to an as yet unexplored recovery phenomenon which occurs between pulses. The session was concluded with a paper³ by Chloride Industrial Batteries of the U.K. which described their latest lead-acid aircraft batteries. Energy density is 22 Wh/kg, about twice the capacity attainable a decade ago.

The Edison nickel-iron battery, which has greater mechanical strength and higher theoretical output than the lead-acid battery, has been refined and applied to electric vehicles by Westinghouse Corp.¹⁰ In a very thorough program, the battery has been developed and tested in three road vehicles for over 15,000 miles. Energy density for the new battery is approximately 50 Wh/kg, twice that of the lead-acid battery.

Several papers^{27,28,29} explored the basic chemistry and optimum design of the LeClanché cell, the familiar primary Zn-MnO₂ "dry cell." Ion transport within the electrolyte, which largely controls the performance of the LeClanché cell, was discussed by the Fysisk-Kemisk Institut of Denmark.²⁷ ESB, Inc. of Wisconsin²⁶ described a thin, flat battery especially designed for high power density.

This work in improving older types of cells by applying the latest technology is surely an essential first step in the systematic development of more efficient sources. It is worth noting, perhaps, that the highly refined older cells have energy density efficiencies of about 20%.

Progress in Secondary Cells

From the older systems the Symposium moved into more recent developments such as Ni-Cd batteries, with papers on improved plate design, better manufacturing techniques, and the use of plastic for structural parts. A Russian paper¹³ described a process in which electrodes are formed from powdered active materials bonded together by an alkali-resistant plastic. The familiar problem of damage from over-charging was investigated by the Ever Ready Co., Ltd., of the U.K.¹² and found attributable to the formation of a Ni-Cd alloy of lower electrochemical potential.

Two papers described work with sealed, secondary Ni-H₂ batteries. The chief merits over Ni-Cd batteries are resistance to damage from over-charge and very long life. High self-discharge rate is the principal shortcoming. The Naval Research Laboratory (Washington, D.C.)¹⁶ estimated a 10-year life for their cell in satellite applications. Union Carbide¹⁷ has developed a D-size secondary cell with an energy density of 40 Wh/kg.

The formidable problem of irregular deposition of zinc during charging of secondary batteries has been successfully attacked by AGA Innovation Center of Täby, Sweden²¹ in a purely mechanical manner. This firm has developed a Zn-Ni battery in which the Zn electrode is

vibrated through ± 2.5 mm at 20 Hz. The technique smooths the deposition of Zn to such a degree that the 1,000-cycle life of the battery is set by the Ni electrode. Tested in an electric road vehicle, the battery was found to be superior in power density to the lead-acid type. Energy density is also higher--50 Wh/kg. The battery may have no advantage over the Westinghouse Ni-Fe battery, however.

Air Batteries

Any battery which uses oxygen as one element of the couple has the obvious advantage that the ambient atmosphere can provide an inexhaustible supply of one of the reactants. Gould, Inc. of Minnesota¹⁹ reported the development of a primary Zn-air "button" cell with twice the capacity of Zn-Hg and Zn-Ag cells. Chloride Technical of Swinton, England²⁰, described a lightweight primary Zn-air battery to replace Ni-Cd batteries in man-portable communications gear.

An ambitious attempt²⁴ to use the high-energy couple provided by Al and O₂ was described by a group from the University of Belgrade, Yugoslavia. Since Al cannot be recovered from aqueous solutions of its salts, the battery is an "exchangeable plate" type of secondary--essentially a primary battery in which replacement of the aluminum electrode constitutes recharge. The electrolyte is NaCl, and one unsolved problem is the growth in volume as Al(OH)₃ is formed during discharge. An energy density of 80 Wh/kg of Al has been achieved, and 200 Wh/kg is considered possible. The theoretical energy density is about 8,000 Wh/kg of Al--far in excess of cells which must carry both reactive components.

An increase in the longevity of the "air electrode," the plate at which O₂ is transferred to and from the electrolyte of a secondary air-battery, has been achieved by the Laboratoires de Marcoussis in France³⁶. They have found that electrodes press-formed from a mixture of Teflon and graphite withstand over 1,000 charge-discharge cycles. In conjunction with techniques being developed to control Zn deposition (several were referenced), they believe that their electrode now permits the construction of a Zn-air secondary battery.

There was only one fuel cell described³⁷, an H₂ - O₂ unit developed by the Siemens Co. of Erlangen, Germany. Fuel cells--in reality batteries where both reactants are supplied continuously from external sources--have been extensively developed in the recent past but have failed to find a market because of cost. The Siemens unit produces 6,700 W, or 95 W/kg (0.06 hp/lb), and has a life of 1,000 hours. Efficiency of conversion of chemical to electrical energy is 45%, about twice the efficiency of an internal combustion engine in converting chemical to mechanical energy.

Air batteries and fuel cells alone possess the theoretical energy density to compete effectively with hydrocarbon fuels. The results reported by the Belgrade group, however, (80 Wh/kg obtained in practice vs 8,000 Wh/kg theoretical) illustrate the distance yet to go in metal-air secondary cells.

Calculation of energy density for a fuel cell requires selection of a certain mass of fuel to add to the weight of the cell itself. If five hours' supply of H_2 and O_2 is assumed, the energy density for the Siemens' unit is found to be 400 Wh/kg. This encouraging figure is, however, rather academic in that the bulk of the reactants and the weight of the vessels required to contain them have not been considered. A five-hour supply of H_2 would occupy 1.0 m^3 at 600 psi and might require a vessel mass of 175 kg (aluminum stressed to 30,000 psi assumed). The corresponding supply of O_2 would occupy 0.5 m^3 at the same pressure and might require a vessel mass of 88 kg. These factors reduce the energy density to 95 Wh/kg.

The theoretical energy density for a H_2 -air fuel cell is 16,000 Wh/kg. If the 20% efficiency of energy density now realized in older types of cells could somehow be achieved in fuel cells, 3,000 Wh/kg would be obtained.

High-Temperature Batteries

The quest for higher-energy batteries, and the attendant need to incorporate the more active metals, has led to a class of batteries with one or more molten components. Among the benefits are (1) ability to electrodeposit the metal from a molten salt electrolyte--hence a reversible cell, (2) elimination of shape-distortion problems by use of liquid electrodes, and (3) high mobility of ions in the molten state, i.e., lower internal resistance.

The Catalyst Research Corp. of Baltimore reported the development of a primary thermal battery with a pure (molten) lithium electrode.³⁵ A pyrotechnic heat pellet provides the operating temperature of 500°C . In comparison with older batteries, which depend upon the *in situ* formation of a Li-Ca alloy to serve as one electrode, the higher coulombic efficiency of the new cell increases the energy density by 100 to 200%. A value of 150 Wh/kg was reported.

Development of a reversible chlorine electrode for an Al- Cl_2 battery was described by the Laboratoire d'Electrolyse of Bellevue, France.⁴⁸ The electrolyte in these cells is a molten mixture of NaCl and $AlCl_3$ at the modest temperature of 110°C . The chlorine electrode is a mixture of graphite and metallic compounds such as $MoCl_5$. Charge storage capacities as high as 90 MAh per gram of electrode have been obtained. Previous Al-Cl batteries have been primary units with an external supply of Cl_2 .

From two presentations^{46,47} by the Argonne National Laboratory it appears that development of the lithium-aluminum/iron sulfide secondary battery is well advanced. This cell, which has solid electrodes in a 450°C eutectic of LiCl-KCl, is an outgrowth of earlier work with the Li-S couple. Energy density is in the range 100-150 Wh/kg and power density is greater than 100 W/kg. Life has been extended to several thousand hours, but is limited to several hundred charge-discharge cycles.

The final battery to be discussed here is the sodium-sulfur type, on which three industrial firms made presentations. This cell, which

operates at about 500°C, contains a molten compound of Na and S within which are immersed the anode and cathode. The anode consists of a ceramic shell filled with molten sodium, while the cathode is a graphitic current collector (such as graphite felt) which is saturated with sulfur. In operation, Na ions pass from the anode, through the ceramic container, and combine with S ions produced at the cathode. Energy densities as high as 200 Wh/kg have been achieved.

Experiments with the structure of the sulfur electrode were reported by Brown, Boveri and Co. of Heidelberg.⁴⁵ Rechargeability is improved and internal resistance is reduced by providing passages within the graphite felt of the anode-felt interface, as well as by adding selenium and boron to the sulfur.

Reactions at the interface between the graphite and the melt have been studied by Chloride Silent Power, Cheshire, England.⁴⁴ Under certain conditions during both charge and discharge, films form at the interface and produce voltage losses. The same firm also reported a study⁴³ of the interface between the molten sodium and the ceramic (beta alumina) container. It was established that the sodium does not wet the ceramic at temperatures below 300°C and a high contact resistance prevails. Above 300°C, wetting occurs and contact resistance becomes negligible.

APPENDIX

List of Papers Presented

- ¹Effect of grid conductivity on the performance of tall lead-acid cells; Norman E. Bagshaw, Keith P. Bromelow, Jack Eaton, Chloride Industrial Batteries Limited, Clifton Junction, Manchester, England.
- ²Potential distribution in the lead-acid battery grid; William Tiedemann, Corporate Applied Research Group, Globe-Union Inc., Milwaukee, Wisconsin, John Newman, Department of Chemical Engineering, University of California, Berkeley, Frank De Sua, Florida Institute of Technology, Melbourne.
- ³Modern lead-acid battery designs for aircraft; Norman E. Bagshaw, Keith P. Bromelow, John Kirkpatrick, Chloride Industrial Batteries Limited, Manchester.
- ⁴The behavior of lead-acid batteries under pulsed discharge conditions; Marcel G. Jayne, Faculty of Science and Technology, Gwent College of Higher Education, Newport, Gwent, Wales.
- ⁵A rechargeable PbO₂ - system in sulfuric acid with soluble negatives; Peter Faber, RWE Electrochemie, Karlstein, FRG.
- ⁶Kinetic investigations on a PbO₂ ring disc electrode; Jürgen P. Pohl, Hans Rickert, Lehrstuhl für Physikalische Chemie, Universität Dortmund, West Germany.
- ⁷The cyclic voltammetry of lead and of a lead-antimony battery grid alloy in aqueous sulfuric acid at 25°C to -40°C; T. Godfrey Chang, Maurice M. Wright, Cominco Ltd., Sheridan Park, Mississauga, Ontario, Canada, Eugene M. L. Valeriote, Defence Research Establishment Ottawa, Ontario, Canada.
- ⁸Sealed nickel cadmium and lead-acid batteries; comparison of functioning mechanisms; John Atkin, Raymond Bonnaterre, Jean-Francois Laurent, Société des Accumulateurs Fixés et de Traction (SAFT), Romainville, France.
- ⁹Low maintenance battery system for aircraft applications; Wayne S. Bishop, John J. Lander, USAF Aero-Propulsion Lab, Wright-Patterson AFB, Ohio.
- ¹⁰Performance characteristics of a new iron-nickel cell and battery for electric vehicles; J. Birge, J. T. Brown, W. Feduska, C. C. Hardman, W. Pollack, R. Rosey, J. Seidel, Westinghouse Research and Development Center, Pittsburgh, PA.
- ¹¹On the ageing of the nickel-cadmium system; Ronald W. Bramam, Richard J. Doran, Stephen E. A. Pomroy, James Thompson, Materials Department, Royal Aircraft Establishment, Farnborough, Hants, England.
- ¹²A cause of stepped discharge curves in nickel-cadmium cells; Robert Barnard, Graham T. Crickmore, John A. Lee, Frank L. Tye, Ever Ready Company (Holdings) Ltd., Central Laboratories, London N15, England.

- ¹³Plastic bonded cadmium electrodes prepared by a rolling technique; Jiri Jindra, Jiri Mrha, Karel Micka, Zdenek Zabransky, J. Heyrovsky Institute of Physical Chemistry and Electrochemistry, Czechoslovak Academy of Sciences, Prague, Czechoslovakia, Bohumil Braunstein, National Research Institute for Materials, Prague, Zcechoslovakia, Jiri Malik, Vojtech Koudelka, Prazska Akumulatorka, NP, Mlada Boleslav, Zcechoslovakia.
- ¹⁴New processes for the incorporation of the active mass into sintered electrodes of the nickel-cadmium battery; S. Sathyanarayana, M. L. Gopikanth, Department of Inorganic and Physical Chemistry, Indian Institute of Science, Bangalore, India, L. N. Sridharan, Tamil Nadu Alkaline Batteries, Ltd., Madras, India.
- ¹⁵New possibilities in the technology of electrodes for alkaline accumulators; M. Cenek, O. Kouril, J. Sandera, A. Touskova, M. Calabek, Brno Technical University, Department of Electrotechnology, Brno, Czechoslovakia.
- ¹⁶Ni-H₂ Battery Flight Experiment; James D. Dunlop, G. van Ommering, M. W. Earl, COMSAT Laboratories, Clarksburg, MD.
- ¹⁷Nickel oxide-hydrogen cells; Karl V. Kordesch, Sandra J. Cieszewski, Union Carbide Corporation, Battery Products Division, Cleveland, Ohio.
- ¹⁸Hydrogen storage electrodes and hydrogen transfer cells; Frederick A. Lewis, James N. A. Bell, Chemistry Department, Queen's University, Belfast, Northern Ireland, Alfons Obermann, Institut für Physikalische Chemie, Universität, Hamburg, Germany, Romulus V. Bucur, Institute for Stable Isotopes, Cluj-Napoca, Romania.
- ¹⁹Commercial zinc-air batteries; John W. Cretzmeyer, Hans R. Espig, Richard S. Melrose, Gould Inc., Portable Battery Division, St. Paul, Minnesota.
- ²⁰A primary, reserve type zinc-air battery for military manpack applications; L. Langrish, Chloride Technical Limited, Swinton, Manchester, England.
- ²¹High-energy long-life zinc battery for electric vehicles; Otto von Krusenstierna, AGA Innovation Centre, Täby, Sweden.
- ²²A nickel-zinc rechargeable cell of the fixed electrolyte type; S. Tajima, M. Nakamura, T. Mori, Laboratory of Electrochemistry and Inorganic Chemistry, Tokyo Metropolitan University, Japan.
- ²³Improvements to the porous zinc anode under galvanostatic and pulse discharge conditions; John Turner, Philip F. Hutchison, Timex Corporation, Washington, Tyne and Wear, England.
- ²⁴Problems in the use of high-energy-density aluminum-air batteries for traction; A. R. Despic, D. M. Drazic, S. K. Zecevic, T. D. Grozdic,

Faculty of Technology and Metallurgy, University of Belgrade and the Institute of Electrochemistry ICTM, Belgrade, Yugoslavia.

²⁵Influence of MnO_2 structure on e.m.f.-pressure characteristics of the alkaline MnO_2 -Zn battery system; Violeta Z. Leger, Ralph J. Brodd, Union Carbide Corporation, Battery Products Division, Cleveland, OH.

²⁶Design and performance of novel thin flat LeClanché battery; Alf M. Bredland, John W. Paulson, Terry G. Messing, Bernard C. Bergum, Ray-O-Vac Division, ESB Incorporated, Madison, Wisconsin.

²⁷Transport in the LeClanché cell separator during discharge; Sven Atlung, Keld West, Torben Jacobsen, Fysisk-Kemisk Institut, The Technical University of Denmark.

²⁸Change in the properties of acetylene black in mixing mills; A. Sattar Syed, M. Anwar Hossain, Industrial Physics Division, B.C.S.I.R. Laboratories, Dacca, Bangladesh.

²⁹Evidence of interaction between carbon and manganese dioxide; James Caudle, Keith G. Summer, Frank L. Tye, Ever Ready Co. (Holdings) Ltd., Central Laboratories, St. Ann's Road, London N15, England.

³⁰Experience in the use of lithium primary batteries for military field operations; Erik D. Wilmar, Norwegian Army Materiel Command, Oslo Mil/Loeren, Oslo 1.

³¹Reliability of lithium-silver chromate cells; G. Gerbier, G. Lehmann, P. Lenfant, J. P. Rivault, SAFT Département Piles, Poitiers, France.

³²Primary $Li/SOCl_2$ cells III, the effect of the electrolyte and electrode variables on the energy density; Arabinda N. Dey, Per Bro, P. R. Mallory and Co., Inc., Laboratory for Physical Science, Burlington, MA.

³³New silver iodide-bis-sulphonium diiodide solid electrolytes for solid state battery systems; Roger G. Linford, John M. Pollock, Christopher F. Randell, School of Chemistry, Leicester Polytechnic, England.

³⁴High energy density batteries based on lithium anodes and substoichiometric oxide cathodes in organic electrolytes; B. DiPietro V. Filippeschi, G. Pistoria, B. Scrosati, Istituto di Chimica Fisica, University of Rome, Italy, M. Lazzari, Centro Studio Processi Elettrodici del CNR, Polytechnic of Milan, Italy.

³⁵A high energy density molten anode thermal battery; G. C. Bowser, D. Harney, F. Tepper, Catalyst Research Corporation, Baltimore, MD.

³⁶Materials for carbon-based primary and secondary air electrodes; A. John Appleby, Gilles Crepy, Georges Fenillade, Laboratoires de Marcoussis, Centre de Recherches de la CGE, Marcoussis, France.

- ³⁷H₂/O₂ fuel cell assemblies with higher power densities; H. Grüne, H. B. Butbier, K. Strasser, Forschungslaboratorien der Siemens AG, Erlangen, Germany.
- ³⁸Platinum-impregnated pyropolymer refractory composites: a new fuel cell electrocatalyst; Lawrence B. Welsh, Karl J. Youtsey, George L. Havert, Richard W. Leyrle, Corporate Research Center, UOP Inc., Des Plaines, Illinois, Bernard S. Baker, Michale A. George, Energy Research Corporation, Danbury, CT.
- ³⁹Withdrawn
- ⁴⁰Batteries for bulk energy storage on the U.K. electricity supply system; Anthony B. Hart, Alan H. Webb, Central Electricity Research Laboratories, Leatherhead, Surrey, England.
- ⁴¹Rechargeable quinone battery for load levelling; H. Binder, R. Knodler, A. Kohling, G. Sandstede, G. Walter, Battelle-Institut EV, Frankfurt/Main, West Germany.
- ⁴²Preparation of a beta-alumina ceramic for the sodium-sulphur battery using a chemical powder preparation method; Werner Baukal, Hans-Peter Beck, Wolfgang Kuhn, Rolf Sieglen, Battelle-Institut EV, Frankfurt/Main, Germany.
- ⁴³A study of the electrode interface formed between sodium metal and beta alumina solid electrolyte; Allan Gibson, Chloride Silent Power, Ltd., Runcorn, Cheshire, England.
- ⁴⁴An electrode kinetic study of carbon electrodes in polysulphide melts; M.P.J. Brennan, as above.
- ⁴⁵Performance of different types of sodium-sulphur cells; H. Kleinschmager, W. Haar, G. Weddigen, W. Fischer, Brown, Boveri and Company AG, Heidelberg, Germany.
- ⁴⁶Performance characteristics of lithium-aluminum/iron sulfide cells; William J. Walsh, Hiroshi Shimotake, Chemical Engineering Division, Argonne National Laboratory, Argonne, Illinois.
- ⁴⁷Electrode designs for high-performance lithium-aluminum/iron sulfide cells; Eddie G. Gay, Donal R. Vissers, Neng-Ping Yao, Fredric J. Martino, Thomas D. Kaun, Zygmunt Tomczuk, Chemical Engineering Division, Argonne National Laboratory, Argonne, Illinois.
- ⁴⁸Lamellar compounds of graphite for the chlorine electrode in an Al-Cl₂ battery; Suzanne Maximovitch, Guy Bonoel, Nguyen Tan Nghia, Joel Sarra-din, Laboratoire d'Electrolyse du CNRS, Bellevue, France.