DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS

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DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS

Introduction

This is the sixth in a series of bibliographies covering unclassified literature related to the direct conversion of energy. Subject coverage includes thermoelectricity, thermionic emission, photoelectric processes, magnetohydrodynamics, electrochemical processes, energy storage, and energy sources.

Users who are primarily interested in thermoelectricity are referred to the four-part bibliography which preceded the present undertaking. Entitled Thermoelectricity Abstracts, it was issued May (PB 151657) and August (PB 151810) 1959, and March (PB 161301) and August (PB 161714) 1960. Copies may be obtained from the Office of Technical Services, U.S. Department of Commerce, Washington, D.C., 20235, by citing the PB numbers included above, following the dates.

The NRL Library does not have copies of the listed material available for outside loan. It is, therefore, suggested that those desiring access to material cited utilize their usual channels for loan or acquisition.

The majority of the publications referred to should be available for consultation or borrowing at the larger public or research libraries. Research reports can usually be obtained from the Defense Documentation Center (DDC), Cameron Station, 5010 Duke St., Alexandria, Va., 22314, through established borrowing procedures, and from the Office of Technical Services (OTS), by purchase. AD numbers are included, when known, in order to facilitate use of DDC or OTS services.


Translations, when referenced, are usually indicated to be available from SIA (Special Libraries Association Translation Center, located at the John Crerar Library, 86 East Randolph Street, Chicago, Ill.) from LC (Library of Congress, Washington, D.C. 20540) or from OTS (Office of Technical Services, Department of Commerce, Washington, D.C., 20235). Complete information regarding such translations may be found in the issue of Technical Translations designated in the citation.

Suggestions concerning this bibliography are encouraged by the compiler, Miss Eileen Pickempaugh, Consultant in Research Information, U.S. Naval Research Laboratory, Code 2023, Washington, D.C., 20390.
I. ENERGY CONVERSION
A. General Information

4639
Aerospace Corp., El Segundo, Calif.

The investigation concerned the mechanism and integration of the electronic conduction process in organic compounds to provide data for development of new solid-state and energy conversion concepts. Several methods were studied for the preparation of organonitrile compounds whose derivatives may exhibit relatively high conductivities. This led to an interesting and unusual reaction involving anthrone, thionyl chloride and malononitrile resulting in formation of the heretofore unreported 10-dicyanomethyl-eneanthrone. (TAB U63-1-4:19,Feb.15,1963)

4640
AiResearch Manufacturing Co., Los Angeles, Calif.

This report presents an analytical as well as experimental study on extracting electrical power from an ionized gas stream. Included in this report are a literature survey on ion convection generators, principles of ionization with reference to effects of non-equilibrium conditions, space charge neutralization studies, one dimensional flow of an ionized gas and interaction of ions and neutrals. A description of the converter design and a detailed discussion of the experimental results are presented in this report.

4641

Three types of converters of solar energy into electricity are discussed (1) thermoelectric, (2) photovoltaic and (3) thermionic. (Solar En., 7:81-82, Apr.-June 1963)

4642

Devices for converting heat, light, motion and radiation into electrical energy are briefly surveyed. (Instr.Abs., 17:8199, Dec.1962)

4643
California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.

The report covers the design, development, and integration of the components and subsystems comprising the power supply for Mariner Venus spacecraft. Data on the performance of the power system from launch until the end of mission are also presented.

4644
California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.

Research of interest reported includes: Solar energy thermionic (SET) electrical power supply by P. Rouklove, p.7-11; Development of 5-ft D electroformed mirrors by Z. Brozdowicz, p. 11-12; Energy storage by G.M. Arcand, p.13-14; Electrical conversion by R.L. Spencer, p.14-16; and Power systems by E.L. Leventhal, p. 16.

4645
Chang, S.S.L. ENERGY CONVERSION.

This book is a text on non-electromechanical energy conversion. It covers thermoelectric engines, thermionic converters, magnetohydrodynamic engines, photovoltaic effect and solar cells, and free energy and fuel cells.

4646

The colloidal electrohydrodynamic energy converter described changes the thermal energy of a slightly ionized superheated vapor to directed kinetic energy, then to high-voltage electric energy. High conversion efficiency is possible if neutral atoms can be made to condense on the ions, which are being pushed against a retarding electric field. Radiation and radiator requirements of the system are noted. The electric power output attainable should be better than 0.4 kw/lb at 500 kw. Use of
the system for propulsion and internal power for spacecraft is discussed. Performance of Hg, K, Na, and Li as working fluids is described. (Nuclear Sci.Abs., 17:9122, Mar.31, 1963)


There's the theoretical device, sketched by the scientist, promising a new era in power generation. But then come engineer realities, problems for engineers who know costs and can integrate the new device into the overall plant.


In French. The possibility of collecting the electrical power from electrodes plunged in a gas at pressure close to atmospheric pressure, propelled by a rotation movement or to great pressure variations, and exposed to x irradiation was recently shown experimentally (Compt. Rend., 254: 4151, 1962). The phenomenon is particularly sharp with argon. A possible explanation for this energy conversion is proposed. (Nuclear Sci.Abs., 17:17346, May 31, 1963)


Improved power sources and energy conversion systems are an important long range national problem and of immediate military importance. Various direct conversion processes appear promising for the solution of some of these problems. In thermoelectricity, progress in materials has been good, but much remains to be done. Even at this stage a number of valuable thermoelectric devices can be constructed, particularly cooling devices ranging from small modules for temperature control of electronic parts to submarine air conditioning, and small size power generators for various remote locations including long lived satellite missions. Thermionic emission offers light weight power generators for large power supplies for relatively short missions. Magnetohydrodynamics is confronted with imposing problems associated with the high temperature requirements for operation of more than a few minutes duration. Important improvements are in sight, and continued progress is imperative to provide high density power sources for advanced weapon systems. Photoelectric processes show good improvements toward the goals of lower costs and performance in severe environments. Fuel cells offer exciting possibilities for uses ranging from the main power source for submarines to the auxiliary power on short time space missions. (Nuclear Sci.Abs., 17:6551, Mar.15, 1963)


Research progress is directed towards achieving a fundamental advance in the state of the art of energy transmission in spacecraft by a technique heretofore unexplored for this purpose. The technique discussed involves the transmission of radiant energy through a hollow, reflective tube from a heat source to some other location in a spacecraft without intermediate Carnot cycle limited conversion process. This technique is particularly useful for applications in which a significant portion of the total energy requirement is in the form of thermal energy. (TAB U63-2-3:72, May 1, 1963)


In German. In recent years, numerous investigators have concerned themselves with thermionic diodes, magnetohydrodynamic converters, thermocouples and fuel cells; also considers a whole series of wrongly forgotten arrangements. These are the cesium-vapor jet generator, galvanic cells with liquid sodium-amalgam, electrokinetic current generators with porous plates through which flow takes place, thermocells of WeiningeT and ferro-electric arrangements. (Battelle Tech.Rev., 11: 504a, Dec. 1962)


A simplified model is used to calculate the conversion efficiency of a cooled p-i-n structure irradiated by a local source. The operation of a practical device is considered and the potential advantages over the solar cell are noted. (Indust. Electron. Abs., 1:A193, Dec. 1962)
Fuechsel, K.M. DIRECT CONVERSION OF NUCLEAR ENERGY INTO ELECTRICAL OR THRUST ENERGY. Am. Nuclear Soc. Trans., 4:335-336, Nov. 1961. Abstract of paper 32-7 given at winter meeting, November 7-9, 1961, Chicago. A description is given showing how nuclear energy is converted directly into electrical or thrust energy.

Hughes, W.L., Summers, C.S. and Allison, H.J. AN ENERGY SYSTEM FOR THE FUTURE. Inst. Elec. & Electr. Engrs. Trans., IE-10:108-111, May 1963. A technique for the practical utilization of solar energy on a continuous basis to provide bulk power is described. The output of solar energy converters is used to produce hydrogen by pressure electrolysis of water. The energy stored in the hydrogen can be efficiently transformed into electrical energy by the use of hydrogen-oxygen fuel cells.

Survey of available "battery" power sources for selection of optimum power source for sonobuoys, missiles, or other similar devices; power sources described include wind driven impellers, wave boosted battery, weight driven systems, electrochemical cells, solar cells, thermoelectric power generation, thermionic cells, nuclear cells, primary and secondary cells; reserve or delayed action batteries, fuel cells, etc. (Eng. Index, p. 40, July 1963)

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Survey of available "battery" power sources for selection of optimum power source for sonobuoys, missiles, or other similar devices; power sources described include wind driven impellers, wave boosted battery, weight driven systems, electrochemical cells, solar cells, thermoelectric power generation, thermionic cells, nuclear cells, primary and secondary cells; reserve or delayed action batteries, fuel cells, etc. (Eng. Index, p. 40, July 1963)
principles and the practical designs and developments are described. (Elec.Eng. 
Abs., 66:5618, June 1963)

4661
Kilbon, Kenyon. ENERGY CONVERSION. 

New electronic technology, founded upon pains-taking research, is preparing a future era of noiseless generators that function without moving parts to transform heat, light, and chemical energy directly and simply to abundant electric power - first in handy packages for use anywhere on earth or in space, and eventually in great central stations serving urban industrial complexes across the continent.

4662

In French. An important separation of positive and negative electric charges in a jet of ionized vapour, metallic or otherwise (mercury, caesium and water) which tends to condense at room temperature, was found. These pressurized vapours, ionized by a h.f. source, entered through a vent into an expansion chamber which contained several electrodes and in which a partial vacuum had been set up. These vapours, made up of molecules, ions and electrons, traversed the vent and the electrodes and expanded at different velocities and an electromotive force was produced between the electrodes. Also, similar results were obtained by using other ionization processes (flame, ultraviolet light, radioactive elements). The voltage distribution in the hot gas in relation to the electrodes was measured by means of small wire electrodes. The separation of electrical charges was obtained without applying an electrical or magnetic field in the vicinity of the electrodes. The difference of temperature between the electrodes played an essential part in this phenomenon. If the electrodes were at the same temperature, no electromotive force was produced. (Phys.Abs.,66:3996, Mar.1963)

4663

In French. Following proposals for a method of direct conversion of heat into electricity a device is described for directly converting atomic energy into electricity. An experimental device using X-rays as a source of ionization produced on open-circuit potential of 25 V and a short-circuit current of \(22 \times 10^{-9}\) A, and had an internal resistance of about \(10^8\) ohms. (Elec.Eng.Abs., 66:3497, Apr.1963)

4664
Marks Polarized Corp., Whitestone, N.Y. 
THE CONVERSION OF HEAT TO ELECTRICAL POWER 
(Q.Rept.4) (Contract No. 60-0831-c) 
(AD-284 662)

The electrothermodynamics of an electric generator utilizing a charged aerosol was investigated for single and multiloop Carnot cycles. Parameters related to efficiency were established for pressure, temperature and isotermal and isentropic work. The charged aerosol is a new working substance uniquely adaptable to a variety of controlled electrothermodynamic operations. Heat interchange is facilitated between the highly dispersed liquid and gas components of the aerosol. The liquid/gas mass ratio of a charged aerosol controls the modes of operation during expansion or compression, thus enabling the predetermination of isothermal or isentropic operation, by adjusting the liquid/gas mass ratio. Electrical power is extracted during both isothermal and isentropic expansion of the charged aerosol. Compression may be effected by the reverse electrothermodynamic effect. New multiloop aerosol cycles having an overall efficiency of 60-80% appear feasible. (TAB U63-1-1:85, Jan.1,1963)

4665
Massachusetts Institute of Technology, 
Cambridge, Mass. 

Section B, Chapter 6, covers semiconductors and semiconductor devices, thermoelectric processes and materials and energy conversion materials, processes, and devices.

4666
Massachusetts Institute of Technology, 
RESEARCH ON MATERIALS, PROCESSES, AND DEVICES RELATED TO ENERGY CONVERSION. 
68p., Dec.31,1962. (Sci. Rept. 6) 
(Contract Nonr-1841(78))


4667
National Aeronautics & Space Administration, 
Washington, D.C. 
POWER FOR SPACECRAFT, by N.D. Sanders, and others. 26p., Dec.1962.
The subject of this paper is the electric-power requirements for spacecraft. Certain aspects of the interrelation of power requirements, energy sources, and conversion techniques are discussed.

4668

In French. Examination of the problems created by the use of various power-generating systems in satellites and their association with solar and nuclear energy sources. The discussion covers energy requirements, energy sources, energy converters, and systems for the generation of electric power. (Intern.Aerospace Abs., 3:A63-14247, May 1,1963)

4669

An outline is given of the description and operation of supercritical cryogenic systems for storing gases in space vehicles. Considerations of weight, thermodynamics, insulation, delivery rates, materials of construction, fluid delivery rates, and heat leaks are discussed. Data are given for H2, O2, and N2. (Nuclear Sci.Abs., 17:9123, Mar.31,1963)

4670
Republic Aviation Corp., Missle Systems Division, Mineola, N.Y.
A SHORT REVIEW OF SPACE POWER SYSTEM TECHNOLOGY. 42p., May 18, 1962. (NP-12492)

A brief review is presented of various power systems currently available for space vehicles. The systems discussed are solar cells, primary batteries, secondary batteries, fuel cells, solar thermionic systems, nuclear power systems, chemical systems, and microwave power transmission. The pertinent characteristics of the available power systems for space application are summarized and compared with each other for specific power levels and missions. (Nuclear Sci.Abs.,17:12035, Apr.15,1963)

4671

The operating characteristics, advantages, disadvantages, and problem areas of fuel cell systems, solar cell systems, and cryogenic chemical dynamic systems are discussed. System parameters are defined for power levels up to 5 kw and for space mission durations up to 14 days. The limitations of each system are discussed and the system characteristics compared. (Astron.Info.Abs., 7:70,502, Feb.1963)

4672

Discussion of the principles of fuel cell, MHD, and thermionic power generation, and the environmental conditions they produce. The factors to be considered in diode construction and their interaction as they affect materials selection are described. (Intern. Aerospace Abs., 2:7764, Aug.1962)

4673
Sundstrand Aviation-Denver, Engineering and Testing Laboratory, Pacoima, Calif.

A feasibility study was made of the thionine photogalvanic system for converting solar energy to electrical energy. Theoretical and experimental investigations have been made to determine the maximum voltage and power available from the system. The effects of operating conditions as well as solution composition variables on cell performance have been studied. Cell voltages up to 220 mv and power levels up to 1.8u watts were obtained. Estimates of the power, weight, and cast of a photogalvanic cell have been made on the basis of present knowledge. (STAR, 1:92-93, Jan.23,1963)

4674


A technique for the direct conversion of thermal energy into electricity is
considered. It is based on the partial ordering of the random thermal motion of charged particles in a nonuniform magnetic field, which leads to the production of a current and an effective emf.

4675

U.S. Air Force, Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

PROPERTIES OF INORGANIC ENERGY-CONVERSION AND HEAT-TRANSFER FLUIDS FOR SPACE APPLICATIONS, by W.J. Weatherford, J.C. Tyler, and P.M. Ku. (WADD TR 61-96) (AD-267 541)

Various inorganic fluids which may be of potential value for energy conversion or heat-transfer in space applications are examined. The fluids are presented in three distinct classes-liquid metals, nonmetals, and gases. Their characteristics are discussed, and their recommended property values are presented in tabular and graphical form, with detailed documentation of basis and source. In addition, background material is discussed, including thermodynamic cycle, heat transfer, compatibility, and working fluid considerations. Current research activities in this field are summarized. (Astronautics Information Abs., 5:5,593, June 1962)

4676


Section V. Energy Conversion. Studies on regenerative emf cells are continuing with the object of converting nuclear energy into electricity. Research on thermoelectric materials for direct conversion of heat into electricity has continued. Seebeck coefficient measurements in the temperature range from 100 to 900 C have been made on a sintered uranium monosulfide ingot containing one percent by weight uranium oxysulfide.

4677


The concept of a thermo-photo-voltaic(TPV) energy converter is introduced and the device compared with thermoelectric and thermionic converters. Features of the TPV converter are that the entire device is kept at room temperature; potential power densities on the order of 10 w/cm², and potential conversion efficiencies of 30 per cent are possible. Considerations for TPV converter design are presented and compared with solar cells. Use of geometry and thin-film optical filters to improve efficiency is discussed. For a germanium converter operating with a hot source in the neighborhood of 1600°C a p-i-n structure with the absorption taking place in the intrinsic base region is shown to give maximum efficiency. A measured efficiency of 4.23 per cent on an experimental converter with 282 mw/cm² incident energy has been achieved.

4678

Westinghouse Electric Corp., Aerospace Electrical Division, Lima, Ohio.


Purpose of the contract is to develop parametric data for the generation, control, conversion and transmission of electric power for space systems. Ratings to be studied are between one and ten megawatts. This report presents the technical data developed during the first three months.

4679


The present status of each of three methods of conversion of heat or light into electrical power without the use of rotating machinery is surveyed: thermoelectricity, thermionic conversion, and photovoltaic converters. A comparison of practical devices indicates that for some time each method will find specialized applications.

B. Bibliographies

4680

Atoms International, Canoga Park, Calif.


This report presents a bibliography of theoretical and experimental papers which concern the Van Allen trapped radiation belts. A general discussion of past history and conclusions from some experimental data are also presented.

4681

Autometrics, Downey, Calif.


4682

Avco-Everett Research Laboratory, Everett,Mass.

MAGNETOHYDRODYNAMIC POWER GENERATION. A BIBLIOGRAPHY, by B.A. Spence. 39p., June 1963. (AMP 110)
The bibliography was prepared to serve as a reference tool for scientists and engineers interested in the field of magnetohydrodynamic power generation. It was aimed to have a complete and all-inclusive listing of material in print anywhere in the world in the field of MHD power generation. Periodic addenda will be published.


Includes some references to thermoelectric powers.


The bibliography includes about 2900 references to works published between January 1955 and December 1960.


This bibliographic search surveys the literature on fuel cells from 1950 to date, with special emphasis on hydrogen-oxygen, molten salt electrolytes, redox and ion membrane exchange types. (TAB U62-4-5:34, Dec.1,1962)


This report provides a 1946-1961 bibliography of solid state research on I-VI compounds, II-VI compounds, III-V compounds and group IV elements and their compounds.


This search contains 552 references to publications on the SNAP program and related topics. The references were taken from Nuclear Science Abstracts and cover the issues through December 31,1962.

C. Patents


Electrodes can be activated by treating a salt of a slightly basic metal in aqueous solution, followed by an alkaline treatment and water rinse. Salts are Zn, Cr, Al as Al(NO3)3. A single treatment by Al(NO3)3 yields better results than 4 deposits from Ni(NO3)3. The activation is better in the presence of oxidizing anions. (Chem.Abs., 59:1291, July 22,1963)


An electrochemical cell, comprising a positive electrode, a negative electrode and electrolyte therebetween, said negative electrode comprising a layer of electrochemically active zinc material provided on one side only with a coating of copper. (U.S. Patent Off.Off.Gaz., 786:1224, Jan.22,1963)


The battery is a can-type, Zn-Mn system. To increase efficiency, simplify construction, and improve the elec.-tech. parameters, a layer of lacquer containing HgCl2, ZnCl2, and a nitrobase is applied to the inner surface of the can. A layer of starch, forming a separating agent
through swelling, is applied to the lacquer, thus separating the electrodes. The positive electrode is composed of an agglomerate mass and cast immediately inside the negative electrode (the can itself). The latter is insulated by a layer of nondrying organic paste to prevent air from getting through to its working surface. (Chem.Abs., 59: 1291, Jly.22,1963)

4692
Casey, E.J. and Nagy, G.D. METHOD OF INCORPORATING AN ELECTRO-CHEMICALLY ACTIVE CADMIUM COMPOUND INTO A POROUS NICKEL PLAQUE. U.S. Patent 3,068,310, Dec.7,1959. (to Her Majesty the Queen in right of Canada as represented by the Minister of National Defence).

A method of incorporating an electro-chemically active cadmium compound into a porous sintered nickel plaque in the preparation of negative plates for nickel-cadmium storage batteries, which comprises soaking the plaque for at least about 10 minutes in molten Cd(NO3)2.4H2O which has been heated to boiling at a sub-atmospheric pressure, removing the plaque and reducing the cadmium nitrate contained therein by heating the plate in a hydrogen filled container for about 1/2 hour to about 2 hours at a temperature of from about 200°C. to about 300°C. and allowing the plaque to cool in a hydrogen atmosphere. (U.S. Patent Off.Off.Gaz., 785:664, Dec.11,1962)

4693

A fuel cell is composed of a fuel element with a gas such as water gas and an O electrode in a semifluid electrolyte. For example, a fuel element of a silvered Zn electrode at 600° oxidizes CO to CO2. The electrolyte of Li or Na carbonate is kept a suspension in a semifluid melt kept at a few degrees below the eutectic melting temperature. The reaction at the O electrode, \( \frac{1}{2} O_2 + CO_2 + 2e = CO_3^{2-} \), results in a current flow of 0.044 amp./sq.m. with a voltage drop of 0.7 v. (Chem.Abs., 59: 1291, Jly.22,1963)

4694

In a fuel cell for the production of electrical energy by the decomposition of a fuel gas an oxidising gas only, at least one non-consumable electrode composed of a porous intimate mixture of zinc oxide and metallic silver, the said mixture containing at least 1% silver, the pore size of the electrode being such that flooding of the electrode is prevented by surface tension. (U.S. Patent Off.Off.Gaz., 785: 665, Dec.11,1962)

4695

A process for preparing a thermoelectric element comprised of a compacted homogeneous intermetallic compound selected from the group consisting of indium antimonide, indium arsenide, cadmium antimonide and zinc antimonide, comprising, admixing predetermined amounts of two finely powdered metals to form an intermetallic compound selected from the group consisting of indium antimonide, indium arsenide, cadmium antimonide and zinc antimonide, sintering the admixture in an inert atmosphere at a temperature 20°C. to 100°C. below the melting point of the intermetallic compound for from 2 to 15 hours, and compacting the sintered admixture under sufficient pressure and heat to form a compact of desired density and configuration. (U.S. Patent Off.Off.Gaz., 789: 809, Apr.16,1963)

4696

A sealed galvanic cell comprising a cupped metallic container made of a rigid metal and having an electrolyte therein, said cell being sealed at the open end of said cupped container by a seal closure which comprises a cover made of a rigid metal and a seal ring made of a hard di-electric plastic-like material which is not readily wetted nor deleteriously affected by said electrolyte and is characterized by a resistance to cold-flow and a high compressive and shear strength; said cover and container having opposite electrical charges, said cover having a substantial horizontally disposed portion which terminates at the periphery of said cover in a vertical edge; said seal ring having an annular, generally upstanding portion having an inner vertical section which corresponds to said vertical edge of said cover and an outer vertical section which corresponds to a section of said cupped cylindrical container; said annular upstanding portion of said seal ring being interposed between said cover and the inner sidewall of said cupped container with said vertical portions in
juxtaposition with the corresponding vertical portions of said container sidewall and said cover; said annular upstanding portion being in a state of radial compression between said cover and said container sidewall and exerting a force which is normal to said vertical portions of said container sidewall, cover, and annular upstanding portion, and parallel to said substantial horizontally disposed portion of said cover; said force being substantially equivalent to, but not greater than the yield strength of the rigid metal of which said cupped container is formed; and said seal ring having another portion integral with said upstanding portion which physically and electrolytically separates said oppositely charged cover and container at the point of sealing from electrolyte carrying elements of said cell and provides an elongated electric current path between said oppositely charged cover and container when the surface of said another portion is wetted by electrolyte. (U.S. Patent Off. Off. Gaz., 785:665, Dec. 11, 1962)


A system for developing a sudden and sustained increase in gas pressure in a duct, comprising a cartridge adapted to discharge explosion gases into said duct upon being detonated, a container of fluid under pressure having a discharge port opening into said duct, frangible seal means initially blocking said port, and activator means responsive to said combustion gases for unblocking said port, said activator being provided with communicating axial and transverse bores for conducting said fluid from said container to said duct. (U.S. Patent Off. Off. Gaz., 786:1224, Jan. 22, 1963)


A process for treating electrodes for lead-acid batteries of the pasted lead grid type which comprises the steps of rapidly applying pressure of from about 80 pounds per square inch to about 400 pounds per square inch to said electrodes with platens heated to a temperature of from about 225° F. to about 350° F., the faces of said platens forming a seal with said electrode grids which confines the steam generated within the paste to said grids, maintaining said pressure for a period of from about fifteen seconds to about five minutes, then slowly releasing said pressure to permit the gradual release of steam. (U.S. Patent Off. Off. Gaz., 785:810, Dec. 4, 1962)

A high-sensitivity photocell comprising photoconductive indium antimonide sensitive to radiation over a given wavelength range and exhibiting a fatigue effect wherein its sensitivity is greatly reduced upon exposure to radiation of a wavelength shorter than about 0.7 micron, and means enclosing said photoconductive member and opaque to wavelengths shorter than about 0.7 micron but including a portion transparent to wavelengths shorter than about 0.7 micron but including a portion transparent to wavelengths greater than about 0.7 micron and within the said given range and allowing incident radiation of the latter character to impinge upon the indium antimonide, whereby the indium antimonide is prevented from exhibiting the fatigue effect and retains high sensitivity. (U.S. Patent Off. Off. Gaz., 786:572-575, Jan. 8, 1963)


A thermoelectric generator comprising a thermally conductive annular heat dissipating and supporting member formed with a plurality of cylindrical radial bores, thermojunction means spaced from and centrally disposed within said annular member, a plurality of radially extending thermoelements spanning the annular space between said thermojunction means and said annular member and each in registration with one of said radial bores, a junction electrode at the outer end of each of said thermoelements, a separate cylindrical thermally conductive force applying member having a snug coaxial sliding fit within each radial bore with which a thermoelement is in registry, and biasing means cooperating with said annular member and with each of said force applying members for causing the latter to engage and exert radially inwardly directed forces on said junction electrodes to thereby place each of said thermoelements under longitudinal compression. (U.S. Patent Off. Off. Gaz., 786:1223, Jan. 22, 1963)


Improvement of a dry cell in a plastic case such that a porous element which conducts electricity, e.g. Cu or bronze, projects from the Zn lining of the cell and is closely joined to the plastic material of the case, permitting the evacuation of the gas while rendering escape of liquid impossible. (Chem. Abs., 58:6453, Apr. 1, 1963)
defining air intake openings for said first and second passages, and said blowers being arranged to draw air through said apertures and to pump the air in radially outward directions through said passages. (U.S. Patent Off. Off.Gaz., 789:632, Apr.16,1963)

A thermoelectric device which generates power at 110° to 925°C comprises a first element of boron in combination with 0.05 to 45% (wt) Ge, a second element in electrical and thermal contact comprised of C, Cu, Ag, Ni, Co, Fe, Re, V, Hf, Nb, Ti, Ta, Be, and/or oxides, borides, carbides, silicides, or nitrides of Ni, Co, Fe, Re, V, Hf, Nb, Ti, Ta, or Be, and external leads connected to the elements. U.S. 3,081,362 - In a device which generates power at 110° to 1950°C, the first element comprises B and 0.05 to 17% Be, and the second element may contain Rh or Ru instead of Hf or Be. U.S. 3,081,363. - The first element comprises B with 0.05 to 45% Zr, and the second element may contain Si. U.S. 3,081,364. - The first element comprises B with 0.05 to 45% Sn. U.S. 3,081,365. - The first element comprises B with 0.05 to 45% Hf. (Am.Ceram.Soc.J., 46:194, Jly.21,1963)

A thermoelectric composition consisting essentially of the material characterized by the formula BiSbTe$_1$.49+1.47a wherein a is between about 3.1 and about 4.3, and at least one doping element selected from the group consisting of copper, silver, gold, iodine, bromine, chlorine, potassium, sodium, and lithium, the doping material being present in an amount between about 0.3 and about 3.0 milligrams per gram of final composition. (U.S. Patent Off.Off.Gaz., 787:193, Feb.5,1963)


An N-type thermoelectric alloy consisting essentially of 95 to 70 mol percent lead telluride and 5 to 30 mol percent tin telluride, said alloy containing 0.2 to 2.4 weight percent of a mixture of lead and lead bromide, said weight percent being a percent of the weight of said lead telluride and tin telluride, said mixture consisting of 35 to 65 mol percent lead, balance lead bromide. (U.S. Patent Off. Off.Gaz., 786:1223-1224, Jan.22,1963)


A photovoltaic cell for converting light radiation into electrical energy comprises a layer of silicon carbide formed on one face of a graphite base, a first layer of silicon of one-type conductivity formed on the layer of silicon carbide, and a second layer of silicon of opposite-type conductivity formed on the first layer to define a pn junction. (Am.Ceram.Soc.J., 46:166, June 1963).

The components are coated with a solder in nonoxidizing ambient during ultrasonic pressure oscillation. (Semiconductor Abs., 7:3079, 1959).

Fuel cells containing a combustible substance, e.g. H, and an oxidant, e.g. O, under pressure are provided with means for controlling the temperature and pressure of the electrolyte in the cell so as to obtain the desired output of electrical energy. In Belgium 625,438 (same patentee; by George H. Davis); 11pp., the temperature of the liquid introduced into the cell is controlled by suitable means so as to maintain the desired temperature within the cell. (Chem.Abs., 59:1290, July 22, 1963).

The element comprises a shaped body of thermoelectric material (lead telluride, germanium telluride, or germanium bismuth telluride), a relatively thin unfused low electrical resistance diffusion barrier layer (Co, Cr, Fe, Mo, Si, Zr, and/or Ti) joined to both ends, and a relatively good electrically and thermally conductive metal contact (Cu, Al, Ag, or their alloys) joined to the barrier layers. (Am.Ceram. Soc.J., 46:194, July 21, 1963).

A device is described that directly utilizes the electrical energy emitted from a gaseous or fluid radioactive material by collecting emitted electrons. The device is designed to function under extreme conditions of temperature and/or shock. (Nuclear Sci.Abs., 17:9150, Mar.31, 1963).
compound; forming a suspension of said activated carbon containing adsorbed noble metal; introducing said suspension by deposition into the pores of a thin porous electrode matrix having an average pore diameter substantially greater than the particle size range of said activated carbon powder; and drying said matrix. (U.S. Patent Off. Off. Gaz., 792:737, Jly.16, 1963).


The electrode bodies according to invention should consist of porous resins produced by soldering together grains of resins, e.g. polyethylene; polymers of tetrafluoroethylene, trifluoroethylene, chloroethylene; polypropylene, and others. The desired porosity can be obtained by variation of the grain size and by addition of retarding agents, e.g. Ti oxide. The surfaces of the pores should be coated by colloidal graphite or by carbon black for assuring electrical condition and for protecting the resin against corrosion by the electrolytes. The active material should be introduced in the form of solutions, e.g. lead sulfate or acetate. (Chem. Abs., 58:6454, Apr.1, 1963).


Liquid NH₃ is used as the principal electrolyte solvent in the current-producing cell (CA 53, 7830i). In the present invention a sulfate of a heavy metal below Fe⁺⁺ in the electrochemical series is employed as a depolarizer. The sulfate also serves to regenerate the electrolyte solute so that the present cell is not electrolyte-limited. Since liquid NH₃ by itself is not very conductive, a solute is used to raise the condition. Various solutes are discussed; the NH₄⁺ and Li salts are particularly well suited for this use. The various factors involved in cell construction are discussed and illustrated. Examples of the preparation and operation of the cell system are given. (Chem. Abs., 59:1291, Jly.22, 1963).


Fuel-cell electrolytes containing alkanoamines, e.g. ethanolamine, aminoethylethanolamine, and their derivs., e.g. containing OH, Co, N: groups, which contain <16C atoms provide efficient fuel-cell operation at 25-1850. Conductance of the electrolytes may be enhanced by the addition of materials of high dielectric constant such as urea, formamide, and dimethylformamide. A cell was successfully operated with a metallic Ag-activated C plate as the oxidizing electrode and a bi-porous Ni electrode as the fuel electrode, separated by a solution of ethanolamine. CO and air were passed into the cell, which operated at 100°. (Chem. Abs., 59:1291, Jly.22, 1963).


In Russian. Patent 130547. Transl. of unedited rough draft available from OTS or SLA, no. FTD-Tr-61-172, AD-268 071.

In order to avoid discharge of the electrodes during charging, and to cut-out fully-charged and faulty storage batteries from the charging circuit, triodes are used as the relays for the voltage which actuates the executive unit. (Tech. Trans., 7:648, May 15, 1962).


The thermoelectric generator comprises two circuit members of thermoelectrically opposite semiconductor materials. The two members form a thermoelectric junction, at least one of the members having a varying composition such that its energy gap is graded from one end to the other. (Nuclear Sci. Abs., 17:9148, Mar.31, 1963).


A solar radiation converter comprising means for converting electromagnetic energy into electrical energy, said means adapted to receive electromagnetic radiation lying substantially within a wavelength band of .5 to 1.0 microns, said means including a photoresponsive semiconductor member having a spectral sensitivity to said defined wavelength band for directly converting electromagnetic energy to electrical energy, and an interference 787 u.g.-13 filter bonded directly on said photoresponsive semiconductor member with the filter being in surface engaging relationship with the member for transmitting electromagnetic radiation within

4727


A first thermoplastic resin, e.g., polyethylene, polypropylene, polystyrene, or poly(vinyl chloride) is intimately mixed with a 2nd thermoplastic resin incompatible therewith, preferably in the wt. ratio 1:1/9-3, and with a powdered electrochemical active substance, e.g., and oxide of Cd, Pb, Zn, or Fe, or Ni hydroxide to obtain a plastic mass. The 2nd thermoplastic resin is preferably polyethylene glycol or poly(vinyl pyrrolidinone). The mass is then shaped into elements which are inserted in the respective conducting sheaths for the electrode, and the 2nd resin is washed out from the mixture so as to obtain a porous electrode in intimate contact with the sheath. (Chem. Abs., 57:12256, Nov. 12, 1962).

4728


A storage battery is made with an intermediate plastic layer placed between the electrodes. To the plastic material is added 5-40 wt.% of a compound with an internal space surface area of 10 sq. m./g. These compounds are silica, diatomite, hard rubber powder, activated C, bentonite, vermiculite, clay, or microporous poly(vinyl chloride) or polyethylene. For example, a sheet of 0.0 mm. thickness is made from 25 g. poly(trifluoroethylene), 50 g. methylformamide, 25 g. Me cellulose, 25 g. ZnCl₂, 175 g. formamide, 225 g. water, and 105 g. Aerosil with a space surface area of 350 sq. m./g. The sheet is placed between a Ag anode and a Zn cathode. It is charged with 10 ma./sq. cm. with increase in voltage from 1.16 to 4.5 v. The discharge at 10 ma./sq. cm. lasts 58 minutes with a decrease in voltage from 0.91 to 0.4 v. (Chem. Abs., 59:1291-1292, Jly. 22, 1963).

4729


In a fuel cell, the fuel (H, CO, MeOH, HCOOH) and the oxidants (O, air, or halogens) are activated by a catalyst in suspension in the electrolyte which carries the electrical charges produced by the reaction on the catalyst to the inert electrodes. The catalyst for the reducing agent is Pt or analogs, Ni, Raney Ni, or Ni alloys and for the oxidant Ag, Ag alloys, or activated C. The alkali electrolyte is KOH solution or the acid electrolyte is H₂SO₄ and HClO₄. The anodic and cathodic compartment are separated by a semi-permeable membrane. (Chem. Abs., 59:1291, Jly. 22, 1963).

4730


A method is proposed which excludes the necessity for initial capacitor activation in the sources and enables the efficiency and functional reliability of the energy converter to be raised and its weight, dimensions, and inertia to be lowered. This is attained by connecting a capacitor together with a linear inductance into a circuit operating at parametric resonance at a frequency half of that at which the dielectric heats. The essence of the method consists in alternately heating and cooling the capacitor, the dielectric of which possesses a penetrability which is a function of temperature. As a result of a change in the capacitance of the capacitor a variable electric current is excited in the circuit. (TAB U63-2-3: 25, May 1, 1963).

II. THERMOELECTRICITY

A. General Information

4731


In recent years thermo-electricity has become increasingly interesting in the fields of refrigeration and for the direct conversion of heat into electrical energy. General considerations show that the efficiency of this method is governed by the Carnot cycle and by a material factor known as the "figure of merit." The efficient utilization of thermo-electricity requires materials with a high figure of merit: the discovery of such materials is the task of the physicist. Since the thermo-electric production of energy and electro-thermal refrigeration are based on the same physical phenomena, both can be devolved from the same first principles. These basic principles are described.

Starting from the phenomenological equations which describe the currents of the four specific ice lattice defects (OH−, OH−, doubly occupied and vacant hydrogen bonds), the electrochemical and homogeneous thermoelectric power are calculated for the current-free steady state under the assumption of immobile chemical impurities. The expression for the homogeneous thermoelectric power agrees with the experimental value (1.8 mV/°C) if the energy values obtained from the electrical properties are inserted, and if the diffusivity ratios of the ions D+/D− and of the valence defects D+/D0 are assumed to be much smaller than unity and 1.2, respectively. The formulae are also applied to ice doped with hydrofluoric acid, and the magnitudes of the Seebeck, Peltier and Thomson effects are derived. (Phys.Abs., 66:10899, June 1963).


This column, which is a regular feature of the magazine, is devoted to thermoelectricity, developments and applications. Many commercial devices are mentioned, most of them in the experimental stage.


Discontinuity in thermoelectric power at melting point.

Massachusetts Institute of Technology, Department of Electrical Engineering, Cambridge, Mass. THERMOELECTRIC PROCESSES AND MATERIALS. 14p., Jan.1,1963. (Semiannual Prog. Rept. 4 & 5) (Contract Nonr-1841(51) This report is a combined report covering the period from January 1, 1962 to January 1,1963. The theme which connects the research reported is the relationship between basic properties of materials and their applications as energy converters. The experimental work has been mainly concerned with compound semiconductors. Investigations concerned with properties relevant to thermoelectric energy conversion have been continued and considerations of other types of energy conversion processes have recently been included.
been found to possess superior mechanical properties to presently available material. Bonded and unbonded PbTe (1/4" x 1/4") were found to be capable of sustaining, without any visible damage, a temperature gradient of 510° for over 250 hours.

The technology of thermoelectric refrigeration and power generation is based on the physics of thermoelectricity. The choice of optimum thermoelectric materials requires an understanding of such basic properties of semiconductors as the electrical and thermal conductivities as well as the various thermoelectric effects. These properties, along with the thermoelectric "figure of merit" which they determine, are defined and discussed, first from a phenomenological point of view and then in terms of the electron theory of semiconductors.

The thermoelectric properties of low-mobility semiconductors, in which the charge carriers are localized and the electrical conduction takes place through their hopping motion, have been investigated. The heat of transport (Q*) and the energy lowering (χ) due to the polarization of lattice have been shown related by the expression $Q^* = \chi$, where $\chi$ and $\chi$ are respectively the components due to polarizations associated with the ions in the hot and cold parts of the semiconductor. It has been shown that the contribution of $Q^*$ to the thermoelectric power can be appreciable in some cases. The values of $Q^* / \chi$ have been theoretically evaluated for a face-centred cubic crystal for certain select directions of temperature gradient.

Principles involved in thermoelectricity are reviewed. Any phenomenon involving the interchange of heat and electrical energy may be called a thermoelectric effect, however, the term is usually meant to imply the Peltier, the Thomson, and the Seebeck effects.

The three fundamental effects of thermoelectricity—Seebeck, Peltier, and Thomson—are presented and the corresponding coefficients are defined. Following a simplified derivation of the Kelvin relations, a more sophisticated and detailed presentation of the irreversible thermodynamic approach to these relations is made. It is demonstrated that these relations are valid in spite of the arbitrary assumptions as to the separation of thermal and electrical conduction made in the former derivation. Next, a brief summary is given of a derivation of the expression for the Seebeck coefficient based on a quasi-free electron model and simple energy dependence of an isotropic relation time. In closing, the attempt to apply band theory to the search for better thermoelectric materials is very briefly described and some interesting ideas for improvement are mentioned along with criticisms concerning predictions of the maximum possible figure of merit.
of carrier and only the role of acoustic phonon is considered.

17

4748


In French. The author develops a generalization of the (average energy gain) method which permits a description of the phenomena caused by an applied electric field and a temperature gradient, in the presence of a magnetic field. One straightforward calculation gives the general expression for the electrical conductivity and thermoelectric-power tensors.

4749


In French. After consideration of the historical definition of the Peltier effect, an up-to-date version is given as the amount of heat involved at an isothermal junction of two phases traversed by an electric current when the irreversibility of the phenomenon is negligible. In the particular case of an electrochemical system, it is the quantity of heat liberated by the reversible passage of a mole of the electroactive ion from one phase to the other. (Phys.Abs., 65:23484, Dec.1962).

4750


The relation between the thermoelectric figure of merit and the basic properties of the material such as carrier mobilities, band structure, thermal conductivity and minority carrier lifetime is discussed. For isotropic materials with parabolic bands it is shown that the figure of merit based on the Seebeck coefficient will increase when a magnetic field is applied, if acoustic-mode scattering is predominant. If optical-mode scattering is predominant, the figure of merit will increase if $ZT>0.77$. Materials for devices based upon the Nernst or Ettingshausen effects will have large figures of merit only if 1) $\mu e^2/k$ is large, 2) the energy gap is less than $kT$, and 3) the electron and hole mobilities are similar. Materials requirements for Nernst- and Seebeck-type devices are compared.

4751


The Seebeck coefficient (S) for a particular orientation of a bismuth single crystal at 78°K changes by 40% when a transverse magnetic field (B) of 10,000 Oe is reversed in direction ("Unkehrreffekt"). The Peltier coefficient (II) also changes by the same proportion, but the field direction which gives the larger Seebeck effect gives the smaller Peltier effect. This is a verification of the modified Kelvin relation, II (B)=TS(-B).

C. Related Phenomena

4752


In French. A comment on the calculation of the electrical conductivity of a crystal placed in a magnetic field. It is noted that measurements of conductivity, magneto resistance, thermoelectric power and Nernst effect provide insufficient data to determine the energy band structure of crystals of high symmetry. (Phys.Abs., 66:6565, Apr.1963)

4753


Initial e.m.fs. of thermocells of AgCl, AgBr, and AgI based on data in the literature differed for cells of common cations. The differences were due to differences in the reversible entropy change. This fact suggested that the heat transported by anions was nearly the same for Cl-, Br-, and I-. For the cells of different cations with identical electrodes, the variation in the initial e.m.f. mainly came from the difference in the irreversible entropy change; the difference in the heat transported by cations was high in this case. The initial e.m.f. of a cell, AgI/HI, was estimated. (Chem.Abs., 58:5255, Mar.18, 1963).

4754


The thermal e.m.f. was studied in steels Kh18N9, Kh18N9T, Okh18N9, and Okh18N9T during heating. The curves of thermal e.m.f. vs. temperature were plotted

D. Materials

1. Measurements

4755

p.1-4, Section I. THERMOELECTRIC PHENOMENA, by Lyle Slack. The thermoelectric investigations are continuing with the redesign and reconstruction of the apparatus for measuring thermal conductivity of semiconductors by the series comparative method.

4756

A study was made of impurity transport in thermal gradients and other fields in materials potentially useful for thermoelectric, thermionic or photovoltaic power generation at high temperatures. The general problem of impurity distributions in an intense thermal gradient was considered. The physical and chemical properties of SiC were considered in the context of diffusion phenomena and thermoelectric behavior at elevated temperatures. Single crystals and polycrystalline rods of SiC were studied. Both chemical and spectrographic analyses were used for the qualitative and quantitative estimation of impurity content. Electrical resistivity and thermoelectric power measurements were made up to 1000 C. Polycrystalline SiC rods were subjected to intense thermal gradients by direct inductive coupling at 5 mc. Impurity redistribution is followed by spectrographic analysis. (TAB U62-1-4:122, Feb.15,1962).

4757

An apparatus for measuring the Seebeck Coefficient of pellets of "N" and "P" types of lead tellurides was built and operated. The apparatus will measure the Seebeck Coefficient as a function of temperature in the range extending from 350°F up to the melting point of lead telluride. With proper operating technique and applying corrections for known systematic errors, the probable error in the results is less than 20%.

4758

An apparatus is described for making direct measurements of small Peltier coefficients of the order of 1 mv and less below room temperature. The Kelvin relationship between the thermopower and the isothermal Peltier coefficient is shown to hold for the copper-lead couple from 7.40 to 298°K.

4759

A new technique has been developed for measuring the thermal diffusivity of small samples in which an IBM 650 computer has been used to perform the calculations. The samples were in the form of round rods of finite length, surrounding a cylindrical guard fabricated from the same material. This method has been shown to give values of thermal diffusivity for Armco iron, from room temperature to 1100°C, which are in good agreement with those obtained by other methods. Preliminary measurements have also been made on a silicon single crystal over the same temperature range.

4760

A modification of the Harmen 'Z-meter' technique for the measurement of the thermal conductivity of thermoelectric materials is described. Heat losses are taken into account in the thermal conductivity equation, and an experimental technique derived which enables the losses to be eliminated. The theory is tested by measurements on a specimen of FeSi2-4%CoSi2 alloy.

4761

In Swedish. A modification of the Battelli Memorial Institute method is described.
The voltage across the sample is measured when current is first applied and when thermal equilibrium is reached, using the step of oscilloscope deflection when switches are closed. (Elec.Eng.Abs., 66:4694, May 1963).


During the progress of an experiment on an alkali-metal plasma (the Q-1 device), it was found possible to measure the Seebeck coefficient, or the thermoelectric power, of the plasma. This note describes the measurement and compares the result with a calculation based upon an approximate theory.


A method is described for the measurements of thermal diffusivities of small samples of semiconducting materials. Results of measurements on InSb and GaAs are given. It is shown that in some cases the simple theory of Angstrom's method must be modified to include some other mechanism of energy transfer, possibly that of ambipolar diffusion.

2. Properties


The Seebeck coefficient \( a \), of InSb-AlSb, 25% InSb-75% AlSb, and pure InSb or AlSb (all p type) was determined at 90-700°C. For InSb-AlSb, increased with temperature to a maximum of 450 \( \mu \text{V} \)/degree at room temperature then decreased rapidly. The \( a \) of 25% InSb-75% AlSb was determined \( \approx 460°C \), where it approached maximum at \( \approx 600 \mu \text{V} \)/degree. From these data the possible limiting Fermi levels and the effective masses were calculated. The latter were \( \approx 0.2m_0 \) for InSb and \( \approx 0.5m_0 \) for the other computation. (Chem.Abs., 58:998, Jan.21, 1963).


Electrical conductivity and thermoelectric power of pressed samples of polycrystalline indium oxide (In2O3) powder were measured in air as a function of temperature from 180 to 460°C.


The variation of the thermoelectric power \( \sigma \) and the electrical conductivity \( \sigma \) with uniform (omnidirectional) pressure up to 9000 kg/cm² applied at room temperature to single-crystal n- and p-type samples of PbTe and PbS was measured. Oil was used as the pressure-transmitting medium.


The effects of pressure on the thermal EMF's of several metals commonly used in thermocouples have been measured over a range to 10,000 bars and 400°C. The method used is essentially that of Bridgman, where the correction is measured on a thermocouple composed of one leg of normal, and the other of compressed metal. By combining the results for the two legs of a thermocouple algebraically, one may obtain the correction to the readings of a thermocouple under pressure. Graphs and power series representations of the data for some common thermocouples were presented. (Solid State Abs., 3: 15,613, 1962).


The thermal conductivity, electrical conductivity, Hall coefficient and thermoelectric power of Ag2Se have been measured between 80 and 600°C. In the low temperature semiconductor phase the thermal conductivity increases with increasing temperature due to the high amount of carrier contribution. The latter has been calculated using the Price formula. Agreement with experiment is satisfactory. The specific heat has been measured between 30 and 200°C. For the
latent heat a value of (5.7±0.5)cal/gr was determined in agreement with measurements of Bellati and Lussana. In addition to the transition at 133°C an unknown new transition has been found at about 90°C.

4769

The thermoelectric power and electrical conductivity of germanium bombarded by fast neutrons in the reactor at Swierk have been measured simultaneously as functions of the irradiation time in the neighbourhood of the intrinsic region of conductivity, vs. irradiation time, and using the theory of thermoelectric power, the dependence of the thermoelectric power vs. time of irradiation has been calculated and compared with experiment. A good agreement has been found indicating the internal consistency of the theory of thermoelectric power and conductivity. Some evidence has also been found to support four the number of minima in the conduction band of germanium.

4770

Thermoelectric properties of n-type Bi$_2$Te$_{2.7}$Se$_3$ doped with Cu, CuBr, CuBr$_2$, BiClO and BiI$_3$ are studied. The lattice thermal conductivity is 1.03 W/m deg K and $\alpha_0$ (m$^2$/m)S parallel to the cleavage plane ranges from 0.036 to 0.052 m$^2$/V sec giving an optimum Z-value of 3.0 x 10$^{-1}$ (°K)$^{-1}$. Galvanomagnetic studies give a band structure close to that of n-type Bi$_2$Te$_3$. The effective mass m* is 0.57m$_0$ and the anisotropy factor for Hall effect measurements with p$_{123}$ equals 0.24. The number of charge carriers related to the amount of doping molecules is discussed. (Phys.Abs., 66:10895, June 1963).

4771

The thermoelectric properties of p-type alloys of the composition Bi$_4$Sb$_{60}$xTe$_{50}$xSe$_{50}$ have been studied for 4 ≤ x ≤ 12. The lattice thermal conductivity is found to decrease when the tellurium content is increased in excess of the stoichiometric composition x = 12, whereas the quantity $\alpha_0$(m$^2$/m)S/2 is relatively constant. A maximum figure of merit Zp=3.2 x 10$^{-3}$ (°K)$^{-1}$ is found for x=8.

4772

Melting point data, metallographic examination and X-ray powder patterns of sections of zone-refined ingots of composition AgTiTe indicated that this material was a ternary compound. Electrical measurements showed that AgTiTe was a p-type semiconductor with a high resistivity and a high thermoelectric power. The temperature variation of resistivity for a purified sample suggested a forbidden energy gap of about 0.65 eV. (Phys.Abs., 66:874, Jan.1963).

4773

A wide range of compositions of the title system have been prepared with x ranging from 0.10 to 0.99, and pertinent thermoelectric properties such as Seebeck coefficient, electrical resistance, and thermal conductivity were determined. Particular emphasis was given to the range of x from 0.95 to 0.99, where useful thermoelectric properties yielding figures of merit between 0.5-0.9 x 10$^{-3}$ deg$^{-1}$ are experienced at elevated temperatures.

4774

n-Type Ge may be transformed into p-type Ge by fast neutron bombardment. The dependence of the Hall coefficient and thermoelectric power on the carrier concentration was measured. The results support the assumption that the number of minutes in the conduction band of Ge is 4. (Chem.Abs., 57:14552, Dec.10,1962).

4775
Centre d'Etude de l'Energie Nucleaire, Mol, Belgium.


Several runs were made to prepare single
crystals of UO₂ for studies at CEN and for satisfying requests from other institutions. The gyration method for spheroidization of single crystals was improved. An equipment for the sintering experiments and for observation of the necks formed between the particles was constructed. The thermoelectric power of three single crystals of UO₂ was measured between 170°K and 320°K with a slightly modified apparatus. From the sign of the Seebeck coefficient, it follows that the conduction in UO₂ is of p-type in the temperature region investigated. The curves show a rather constant value for the thermoelectric power as a function of the temperature. (Nuclear Sci.Abs., 17:16642, May 31, 1963).


The thermoelectric powers (TEP) of copper alloys containing dilute amounts of iron, cobalt, or chromium and up to 10 at. % manganese or nickel have been measured between 4.2° and 1000°K. Similar alloys of gold have been measured between 4.2° and 100°K. The individual solutes produce comparable effects in either solvent.


The thermoelectric power of NaCl has been measured as a function of temperature between 550°C and the melting point, using Pt-metal electrodes. Measurements were made on pure material, and also on material doped with 0.1% CdCl₂. Compared with the theory of Howard and Lidiard, the results yield a value of the order of -1 eV for the sum of the cation and anion vacancy heats of transport, although the accuracy is low because of reactions occurring at the electrodes and uncertainties in the ratio of defect mobilities.


New measurements of the Hall coefficient and absolute thermoelectric power of liquid gallium are reported. The former has the 'free electron' value. All known electron transport properties of liquid Ga are collected and discussed in relation to the recent theory of Ziman. Previously unpublished x-ray diffraction observations are quoted and used.


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A study of cerium sulfide, Ce₃-xS₄, over most of the range of composition, 0<x<1/3, has led to information about the conduction band. The compositions, determined by accurate density measurements, permitted evaluation of the electron concentration,n. The room temperature values of the electrical conductivity σ, the thermoelectric power α, and the Hall coefficient Rₓ, were determined as a function of n over the range from 6 x 10²⁰ cm⁻³ to 6 x 10²¹ cm⁻³. The mobility is relatively low (2-3 cm²/V-sec), but the thermoelectric power varies as n⁻²/₃, as required by conventional theory for degenerate systems, and this permitted estimates of the effective mass and width of the conduction band. On the other hand, the Hall coefficient decreases below the value l/ne as n is increased, indicating warping of the Fermi surface as the conduction band is filled. These results, and the analogy to transition metal oxides, suggest the possibility that the conduction band arises primarily from overlapping 5d orbitals of the cerium ions.


The thermoelectric properties of liquid tellurium have been studied at temperatures ranging between 400° and 500°C both for pure tellurium and for solutions containing up to 20% (by weight) of selenium. This included measurements of the electrical conductivity σ, the Seebeck coefficient α, and the dimensionless figure of merit γ=α²T/κ and from these the thermal conductivity κ was derived. The measurements were made entirely by electronic methods in a sealed Pyrex tube containing platinum and platinum-rhodium leads. The figure of merit was obtained by the small area contact method devised by one of the authors. For liquid tellurium, our results for α,σ, and κ agreed with values which have been obtained previously by other investigators. The unusually large value of κ observed in liquid tellurium is found to decrease upon addition of selenium. This, and the behavior of α and σ indicate that selenium tends to reduce the concentration of electrons in comparison to that of the holes. At higher concentrations of selenium, phenomena are observed which seem to be related to the motion of ions.
The thermoelectric power of chromium against copper has been investigated in the range 30-40°C using 20 specimens of chromium varying in purity, grain size and state of strain. In all cases there is a sharp fall in thermoelectric power as the temperature rises through -35°C. For all high-purity specimens this transition temperature is in the range 35-350.8°C. The strength of the anomaly is affected very little by variations in the interstitial impurities nitrogen and oxygen, but is clearly influenced by small strains in the material and by changes in grain size. The results are considered in terms of anti-ferromagnetic ordering and the influence of internal stresses on domain structure.


Polymers of Cu-phthalocyanine were prepared and the electrical conductivity, thermal conductivity, Hall effect, and thermoelectric power were determined. Two forms of the polymer were studied; when the low-temperature polymer was heated to 250-350° a new form arose. The low-temperature form had an activation energy of 0.26 e.v., p-type conductivity, thermoelectric power of 15 µv./degree, and a thermal conductivity of 9 x 10^4 cal. cm./sec. degree at 25°. The heat-treated form had an activation energy of 0.12 e.v., p-type conductivity and thermoelectric power of 35 µv./degree. (Chem.Abs., 57:14529, Dec.10,1962)

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The thermo-emf of germanium single crystals alloyed with arsenic, antimony, and phosphorus has been investigated over a wide range of impurity concentrations up to values approaching the solubility limit.

4789

The absolute Seebeck coefficient, electrical resistivity, and thermal resistivity were simultaneously measured on pure bismuth single crystals of various orientations between approximately 80° and 300°K. Using an overlapping two-band many-valley model, numerical values for the temperature dependence and anisotropy (where appropriate) of the following parameters have been calculated: (1) the overlap energy and the Fermi energy of the electrons and of the holes, (2) the density of states effective mass of the electrons and of the holes, (3) the separate electronic and lattice thermal conductivities, (4) the actual index of thermoelectric efficiency, and (5) the hypothetical "optimum" index of thermoelectric efficiency. The calculated electronic thermal conductivity includes a new term due to bipolar diffusion.

4790
General Atomic, San Diego, Calif.

A study of cerium sulfide has improved understanding of its metallurgy and basic electronic properties. Results indicate that cerium sulfide and related compounds have potential value as thermoelectric materials at temperatures between 500°C and 1200°C. A study of phase stability shows that pure cerium sulfide is unstable at the temperatures of potential application; however appropriate doping of pure cerium sulfide with alkaline earth elements can prevent conversion to other phases.

4791
General Telephone and Electronics Laboratories, Inc., Bayside, N.Y.

A new technique was developed for the investigation of the thermoelectric power of hot carriers. A thermoelectric potential was observed in Ge due to the application of a high intensity pulse of 69 Gc power. A semi-quantitative theory was constructed for the analysis of the data.

4792
Gmechling, Werner and Hagmann, Dieter.

In German. The temperature coefficient of resistivity and Hall constant at room temperature were measured on alloys of Pd with Ag, Cd, In, Rh, Ru, Mo, Nb, Zr, and V. Starting from pure Pd, the absolute temperature coefficient of resistivity $\Delta_{\rho}/\Delta T$ is decreased by all alloying additions. This fact is mainly due to the filling up of the d-band by the electrons of the solute. The amount of the absolute temperature coefficient of the Hall constant $\Delta R/\Delta T$ also decreases in every case. This change is far more pronounced than that of the temperature coefficient of resistivity and leads to a change of sign for many alloys at additions of only 2 at.% alloying element to Pd. This effect is also connected with the d-band of Pd. Comparing it with the behavior of the thermoelectric power of...
these alloys, however, suggests that this pronounced change is mainly caused by the scattering of the electrons at solute atoms. (Nuclear Sci.Abs., 17:580, Jan. 15, 1963).

4793

The conductivity, Hall effect, and thermoelectric power of HgSe single crystals are measured between 90 and 500°C.

4794

To determine the nature of the variability in thermoelectric properties a previously described application was used to measure the thermo-e.m.f., E, of crystals of magnetite, magnesioferrite, jacobite, pyrrhotite, and molybdenite from various deposits of the U.S.S.R. and of certain varieties of crystals of cassiterite which had been previously considered as nonconductors of electricity. (Chem. Abs., 58: 3999-4000, Mar. 4, 1963).

4795

The magnetic-field dependences of the electrical and thermal resistances, the thermoelectric power, the Hall, the Right-Leduc, the Peltier, and Ettingshausen effects at liquid-helium temperatures in magnetic fields up to 14 kG, have been investigated in a single crystal of zinc. The measurements were taken with either a constant heat current or a constant electric current flowing perpendicular to the hexagonal axis and with the magnetic field parallel to the hexagonal axis.

4796

Following earlier measurements on pure potassium and alloys, the authors have now made a corresponding study at very low temperatures of thermoelectricity in rubidium, caesium, and their alloys with each other and with potassium. The results have proved in accord with the interpretation of the earlier work, and the trends observed in both the 'electron diffusion' and 'phonon-drag' contributions to the absolute thermoelectric power are discussed. Both contributions as observed in these metals are consistent with a larger distortion in the Fermi surface of caesium than in those of potassium or rubidium. It appears that the changes in the thermoelectric diffusion term can be attributed consistently to the difference arising from large-angle and small-angle scattering. It is supposed that in turn these types of electron scattering arise from the presence of homovalent and heterovalent impurity centres.

4797


The temperature dependences of the electrical conductivity, Hall effect, thermoelectric power, and Nernst-Ettingshausen effect, as well as the magnetic field dependence of the resistance and Q, were investigated for polycrystalline and single-crystal CdSb of stoichiometric composition or alloyed with copper, gallium, indium, germanium, tin, lead, selenium and tellurium. The forbidden bandwidth at absolute zero was deduced from the experimental results: It was 0 = 0.58 ev. The temperature dependence of the mobility in the impurity region was deduced from the Hall effect and conductivity, but in the intrinsic region it was deduced from the temperature dependence of the Nernst-Ettingshausen effect. The ratio of the effective masses in the intrinsic region and the effective masses of holes and electrons in the impurity region at 100°C were also determined. It was established that the impurities affect the sign of conduction, carrier density, thermoelectric power and other properties of CdSb.

4798

Preliminary measurements have been made on the electrical resistivity and thermoelectric power of plutonium oxide in the composition range of PuO1.70 to PuO2.00 from 20 to 1000°C. The normal PuO2-x composition which results from the vacuum sintering of PuO2 has been shown to exhibit a-type conductivity at room temperature. This change on heating to
n-type which is characteristic of oxygen deficient PuO$_2$-x. Room temperature resistivity and low temperature activation energy varies directly with oxygen content. The activation energy for electronic conduction for PuO$_2$-x is 0.52 ev over a wide range of oxygen content, while the intrinsic activation energy for PuO$_2$ is 1.8 ev.

4799

Upon zone-refining indium-antimonide, ultimate concentrations of two slowly segregating impurities are approached. The most slowly segregating impurity, identified as tellurium, was found to be n-type which lowers the melting point of indium-antimonide. The second most slowly segregating impurity, identified as zinc, was shown to be p-type which raises the melting point of indium-antimonide. Both impurities originated in the indium.

Electrorefining is an effective technique for removal of zinc from indium. Zone-refining is an effective technique for removal of tellurium from indium. There are no indications that deviations from stoichiometry prevent the attainment of extrinsic carrier concentrations below $10^{14}$/cm$^3$ in indium-antimonide.

4800

The resistivity of high-quality single-crystal germanium is determined by its impurity content and, in turn, resistivity can be used as a measure of purity. The semiconductor device engineer will find it most convenient to specify germanium purity in electrical terms by its conductivity type (n or p) and its resistivity at some standard temperature such as 25°C. In this paper, the temperature variation of resistivity over the range -100°C to +140°C has been calculated and plotted for both n-type and p-type germanium with different impurity content, ranging from 0.1 ohm-centimeter to 60 ohm-centimeters at 25°C.

4801

This Note describes some simple chemical properties of these thermoelectric materials relevant to their incorporation into practical devices.

4802

Discussion of properties of metals, semiconductors and insulators to estimate their values as thermoelement material; equation for figure of merit; semiconductors appear to remain most favorable materials for use in thermoelectric cooling. (Eng.Index, p.188, June 1963).

4803
Irie, T., Takahama, T. and Ono, T. THE THERMOELECTRIC PROPERTIES OF AgSbTe$_2$-AgBiTe$_2$, AgSbTe$_2$-PbTe AND -SnTe SYSTEMS. J.Appi. Phys. (Japan), 2:72-82, Feb.1963.

Thermoelectric properties of AgSbTe$_2$-AgBiTe$_2$ and PbTe and SnTe systems are studied. In these alloys and also in AgSbTe$_2$, when prepared by the usual method of zone melting, the thermoelectric power and electrical conductivity vary along the length of the bar and the mode of variation depends strongly on the speed of zone-passing. These facts are probably related to the mode of precipitation of Ag$_2$Te or Sb$_2$Te$_3$. The Hall mobility of AgSbTe$_2$, which does not contain the precipitate Ag$_2$Te, was found to change with absolute temperature with an exponent of -0.7 and -1.3 for two specimens. In AgSbTe$_2$-AgBiTe$_2$ and PbTe systems, the electrical conductivity decreases and the thermoelectric power increases with increase of AgBiTe$_2$ or PbTe content. In the AgSbTe$_2$-SnTe system, the electrical conductivity increases and the thermoelectric power decreases with increase of AgBiTe$_2$ in the AgSbTe$_2$-AgBiTe$_2$ system while it has a broad minimum in the range of PbTe content from 20 to 60 at.% in the AgSbTe$_2$-PbTe system. In AgSbTe$_2$-SnTe the lattice thermal conductivity increases with increase of SnTe. (Phys. Abs., 66:10900, June 1963).

4804

The absolute thermoelectric power of single crystals of AuSn has been measured between 2-5°K and room temperature for various orientations with respect to the hexagonal axis. The results exhibit a very pronounced anisotropy. A maximum is found in the $a$ direction around 25°K and attributed to anisotropic phonon-drag effects. The temperature dependence and the anisotropy are and some speculations are presented regarding the electronic structure of AuSn.
26

4805

Measurements of the electrical resistivity, absolute thermoelectric power and Hall coefficient of AuAl₂, AuGa₂ and AuIn₂ between liquid helium and room temperatures are reported and discussed. These metallic compounds have the cubic fluorite structure.

4808

Thermoelectric power measurements have been made on nonstoichiometric α-Nb₂O₅ over the temperature range from 300° to 1270°K. The measurements show that, for all compositions in the single-phase, α-Nb₂O₅-x region (0.0012<x<0.1545), the majority charge carriers are electrons. These thermoelectric power data have been interpreted in terms of a simple semiconductor exhibiting conduction in a narrow band with the conduction electrons being assigned an effective mass equal to four times that of the rest mass.

4807

The thermoelectric power, electrical resistivity, and thermal conductivity, between room temperature and -800°K, of the pseudo-binary system Ag₂Te-Sb₂Te₃ were measured, and the effect of heat-treatment studied. Results are presented graphically. (Met.Abs., 30:590, Apr.1963).

4808

A preliminary report on some properties of Cu₂S and its alloys with Cu₂Te. The materials are Cu deficient, exhibit hole conduction, and melt between 900 and 1130°. They are semiconductors in the molten state. An alloy of 75% Cu₂Te and 25% Cu₂S was by far superior over other compositions tested. Thermal conductivity is lower in the liquids than in the corresponding solids. The liquid states will not be subject to mechanical failure. A disadvantage is the containment problem. (Chem.Abs., 58:2960, Feb.8,1963).

4809

Changes in thermoelectric force (S) by annealing were measured for Cu and Ni cold-worked at room temperature. In the case of Cu (90 -15% compression), the changes in the region from 120-to 400° are attributed to the disappearance of dislocations (TD). The changes for Ni (80% compression) occurred in two stages, one between 200 and 300° and the other above 400°. These are attributed to the disappearance of point defects(vacancies) (Tv) and dislocations (TD), respectively. (Chem.Abs., 58:3945, Mar.4,1963).

4810

The electric conductivity σ and thermoelectric power e.m.f. α of Mn silicides were studied. From comparison of the values of σ and α (1500-10,000 Ω⁻¹ cm⁻¹ and from +15 to +20 meq./degree, respectively, for Mn₃Si, Mn₅Si₃, and MnSi and 200 - 600 Ω⁻¹ cm⁻¹ and from +70 to 110 meq./degree for the higher silicide Mn₅Si₃) it is concluded that the former has a metallic character and the latter a polymetallic character. (Chem.Abs., 57:14528, Dec.10,1962).

4811

In German. In solid solutions of palladium with platinum, rhodium, molybdenum and vanadium electrical resistivity, Hall constant and their temperature coefficients as well as the differential thermoelectric power have been measured at room temperature. Different properties vary in a similar way. These are susceptibility, electronic specific heat, and the temperature-coefficient of electrical resistivity, as well as Hall constant, its temperature coefficient and thermoelectric force. This fact depends mainly on the exchange of electrons between the solute atoms and the conductivity bands of palladium. All additions to palladium lead to a change in sign of the temperature coefficient of the Hall constant. A comparison with palladium-gold alloys indicates, that this behaviour is not necessary connected with the presence of two conductivity bands.
LaBotz, R.J., Mason, D.R. and O'Kane, D.F. Lashkar'ov, G.V. and Samsonov, G.V. CQARAC-4814 4816

The article provides the results of thermoelectric figure of merit which could be obtained with these materials is not as good as that of other materials now in use.


The article provides the results of approximate calculations of the z parameter of high-melting compounds (z=2/\(n_0^p\), where \(n_0\) is the thermo-emf coefficient, \(n\) is the thermal conductivity coefficient, and \(p\) is the electrical resistivity) and also the results obtained in calculating the efficiencies of thermoelectric generators made of these materials for the case where the hot junction temperature is \(T_1=1200^\circ\text{K}\), and the temperature of the cold junction is \(T_0=400^\circ\text{K}\).


The quality factors and the corresponding efficiencies are calculated for MoSi\(_2\), CoSi, NbSi\(_2\), ReSi, CrN, NbB\(_2\), TiC, MnSi, MnSi\(_2\), ReSi\(_2\), and CrSi\(_2\), Mn, Re, and Cr silicides and CrN have higher thermoelectric efficiencies and possibly may be used as materials for thermoelectric generators. (Chem.Abs.,57:187,Jly.9,1962).


Thermoelectric power, Hall constant, Hall mobility, thermal conductivity (k), and the lattice contribution to k (k\(_l\)), m.p., phase-instability temperature and other properties of CoGeAs\(_2\), CoSnAs\(_2\), ZnGeAs\(_2\), and ZnSnAs\(_2\) were determined. For all the compound, k\(_l\)=T\(^{-1}\) at 300\(^\circ\text{K}\), and its absolute value is less than in InAs. (Inst,Metals, J.,91:794, Jly.1963).

An extensive study was completed on the electron transport phenomena in zinc at liquid helium temperatures. The magnetic field dependents of the electrical and thermal resistances, the thermoelectric power, the Hall, the Righi-Leduc, the Peltier, the Ettingshausen, and the Ettingshausen-Nernst effects were investigated in magnetic fields up to 14 kG. The different kinetic coefficients relating fluxes to affinities were computed and curve fitting of the conductivity coefficients to the Sondheimer-Wilson theory was made in terms of a four-band scheme.

4819

Changes in the Seebeck coefficient and Hall constant have been studied for the system (1-x)M0.024 + (1-x)Ge0.97Te + xBi2Te3 where M stands for the metals, germanium, tin, indium, gallium, titanium, and silver. The solubility of these metals are shown to increase with the addition of "neutral vacancies" introduced via bismuth telluride. A linear relationship is obtained between the log of the carrier concentration and magneto-thermoelectric power depends on the amount of neutral vacancies. The initial solubility is determined only by the ion charge and radius of the solute metal, and the initial carrier concentration in inversely proportional to the charge/radius ratio. An expression satisfying the data is obtained for the solubility as a function of charge, radius, neutral vacancy, and known constants.

4820
Massachusetts Institute of Technology, Laboratory for Insulation Research, Cambridge, Mass.
ELECTRIC AND MAGNETIC PROPERTIES OF V2O5 AND RELATED SESQUIOXIDES, by A.J. MacMillan. 32p., Oct.1962. (TR 172) (Contract AF 19(604)-5482j (Contract NOS-78320). 309 were examined electrically for Seebeck effect and resistivity from 600 to 1200°C; the remaining few failed in test.

The study is concerned primarily with the electric and magnetic properties of V2O5, both in the pure form and in solid solution with other related oxides. Results of thermoelectric power measurements are presented in tables.

4821

In Rumanian. The variation of the thermo-electromotive force of V2O5 both during and after reactor irradiation was studied. During irradiation with a flux of 5 X 1012 n/sec cm² and a gamma dose of 104 r/sec, the thermo-electromotive force begins to increase, reaches a maximum value after 4 to 5 hrs of irradiation, and then returns to its initial value. After irradiation, the thermo-electromotive force keeps the same value as before irradiation. (Nuclear Sci.Abs., 17:12724, Apr.30,1963).

4822

The change in thermoelectric power due to magnetization of ferromagnetic substance, i.e. the magneto-thermoelectric power, and linear magnetostriction at given temperatures are measured on single crystals of Fe-Ni alloy (about 24% Fe). The single crystal behaviour of magneto-thermoelectric power in these f.c.c. crystals are similar to that of magnetostriction. The constants (Em)100, (Em)111 and (K100, K111 which specify magnetothermoelectric power and linear magnetostriction in the (100) and (111) directions, respectively, have been determined. The magneto-thermoelectric power depends on the orientation of the crystal axes and is always negative. The numerical values obtained are as follows: (Em)100=0.84X10^-6 volt/degree, (Em)111=0.53X10^-6 volt/degree and (K100=8.4X10^-6, K111=1.3X10^-6.

4823

Three hundred twenty-three oxide, silicate, and metal hydride combinations were prepared and fabricated into test specimens by a variety of forming and firing techniques. Of these combinations, 309 were examined electrically for Seebeck effect and resistivity from 600 to 1200°C; the remaining few failed in test.

4824
Naval Radiological Defense Laboratory, San Francisco, Calif.

Two satisfactory laboratory methods for detecting and studying transient radiation effects on Seebeck coefficient, S, and electrical resistivity, p, of materials having large thermoelectric figures of merit, z, have been developed. The
Transient effects of intense beams of 2 Mev electrons on z in commercially available, thermoelectric grade bismuth telluride, have been deduced from separate observations of S and o, made using these methods, together with previously reported observations of thermal conductivity. These observations indicate that ionizing radiation has no transient effects on the point value of z, within experimental limits of accuracy amounting to ±50%. However, secondary effects very probably arising from inhomogeneity of the test material were observed. A simple model for, and some of the implications of, these observations are discussed.

4825
Northwestern University, Technological Institute, Department of Materials Science, Evanston, Ill.
THE THERMOELECTRIC POWER IN NONSTOICHIOMETRIC α-Nb₂O₅, by R.F. Jannick and D.II. Whitmore. 9p., Mar.29,1963. (TR 4) (Contract NoIr-1228(16)).

Thermoelectric power measurements have been made on nonstoichiometric α-Nb₂O₅ over the temperature range from 300° to 1270°K. The measurements show that, for all compositions in the single-phase, α-Nb₂O₅-x region (0.0012 < x ≤ 0.1545), the majority charge carriers are electrons. These thermoelectric power data have been interpreted in terms of a simple semiconductor exhibiting conduction in a narrow d-band with the conduction electrons being assigned an effective mass equal to four times that of the rest mass.

4826

Wire specimens were cold drawn at 0° to various amounts of reduction of area and the thermoelectric shifts induced were measured. There are given (1) the variation in e.m.f. with time at 25° after a 20% reduction of area in thermocouple Fe, constantan, Cu, Chromel-P, Alumel, Pt, and 10% Rh-Pt; (2) the effect of 20% reduction of area as a function of temperature in Cu, Chromel-P, Alumel, Pt, and 10% Rh-Pt; and (3) the effect of temperature and of the amount of reduction of area in thermocouple Fe and in constantan. (Chem. Abs., 58:6815, Apr.1,1963).

4827

Equations of the form of the Mott and Jones equations for the absolute thermo-electric powers of metals are derived primarily from a thermodynamic approach. The behaviors of transition thermo-elements in common use are then examined and compared with this simple theory.

4828
Princeton University, Plastics Laboratory, Princeton, N.J.

A series of highly conjugated polymers with semiconducting characteristics, was examined to determine the piezo-resistive behavior. The resistivities ranging from 10² to 10¹¹ ohm-cm at room temperature and 1840 atmospheres pressure, decreased 100, and for some polymers, 1000 fold as the pressure was increased to 35,000 atmospheres. An elementar polymeric semiconductor with high conductivity was also observed to have a decreasing thermoelectric power with increased pressure and a relatively constant activation energy, both due to the p-type TeO₂ impurity.

4829

Measurements of Hall mobility and conductivity at room temperature and of the variation of resistance and thermoelectric power with temperature have been made on antimony telluride films prepared by vacuum evaporation. Results of the measurements show the presence of intercrystallite barriers; the barrier height reduces to one tenth of its value on heat-treatment. An increase in Hall mobility is observed with thickness of the deposited films and in general a small increase is found after heat treatment. Large increase in conductivity is obtained after heat treatment. The thermoelectric power at room temperature reduces to one third of its original value after heat treatment. The results obtained have been discussed.

4830

Sample descriptions, test conditions, and Resulting Thermal Conductances of Thermoelectric materials are presented.

In German. These alloys were studied for their suitability for thermoelectric refrigeration. Basic alloys in the composition range 73 mol.% Sb2Te3 to 27 mol.% Bi2Te3 with 2 to 8 wt.% Te and Se amounting to half to 1/5 of the excess Te added were considered the most suitable.


Single crystals of Cu0.076WO3, Cu0.094WO3, and Cu0.95WO3+6 were prepared by thermal decomposition of CuWO4 and WO3. Potential-probe resistivity measurements in the range 120° to 770°K indicate complex semiconducting behavior. Measurements of the Hall voltage and of the thermoelectric power indicate that carriers are electrons. At 300°K representative carrier densities are 5 x 10^18, 15 x 10^18, and 1 x 10^18 electrons per cubic centimeter with mobilities of 6, 10, and 0.4 cm^2/V-sec for Cu0.076WO3, Cu0.094WO3, and Cu0.95WO3+6, respectively. Thermal emf values fall in the range -220 to -300 µV/°C. Results are interpreted in terms of a conduction band model with destruction of the band below room temperature due to a probable ferroelectric transition in the host lattice. Excess oxygen acceptor centers of appreciable ionization energy apparently are present in small concentration in the low-copper materials and in large concentration in the high-copper material. (Am. Ceram. Soc. J., 46:26, Jan. 21, 1963).


The influence of impurities on the electric and thermoelectric properties of CdSb single crystals prepared by the modified Czochralski method and the method of zone melting was studied. It was found which impurities are electrically active and which give rise to electron and hole conductivity and a schematic model of their substitutions in the CdSb lattice was proposed. The temperature dependence of the mobility was found for both electrons and holes and the density effective masses were determined.

South Dakota School of Mines and Technology, Solid State Physics Project, Department of Physics, Rapid City, S.D. THE EFFECT OF A MAGNETIC FIELD ON THERMAL AND ELECTRICAL PROPERTIES OF MAGNESIUM STANNIDE AND INDIUM ANTIMONIDE, by R.J. Kostelecky. 61p., Nov. 1, 1962. (TR 7) (Contract Nonr-2964(01)).

The measurements performed allowed the determination of (1) the value and the relative change in a magnetic field of the thermal conductivity of InSb and Mg2Sn, (2) the relative change in a magnetic field of the Seebeck coefficient of InSb and Mg2Sn, and (3) the relative change in a magnetic field of the electrical resistivity of InSb.


The thermal expansion, heat capacity, thermal conductivity, total normal emittance, electric resistivity, and thermoelectric voltage were investigated for 26 refractory materials, including the borides, carbides, nitrides, oxides, ATJ graphite, tungsten, and alloys of molybdenum and columbium. The temperature range was from 500°F to 5000°F. In addition to these thermophysical properties, the density, chemical analysis before and after temperature exposure, and microscopic pictures before and after temperature exposure, are included to define the materials and assist in the analysis of the data.


Resistance measurements of pressed pellets of metal-free phthalocyanine ranged from 2 x 10 to the 11th power at room temperature to 8 x 10 to the 6th power ohm-cm at 225°C. An activation energy of 1.385 ev was calculated for conduction; the Seebeck coefficient was -168 micro V/C at 220°C. Liquid semiconductors having thermoelectric properties comparable with Cu2S were produced by addition to Cu2S. The best material investigated to date contained 75% Cu2Te-25% Cu2S. The improvement in the thermoelectric properties of Cu2S for
power generation apparently depends more on lowering the resistivity than by raising the Seebeck coefficient. The Cu-S ratio should be altered by increasing the S content rather than the Cu content. Ag-In tellurides prepared by heating equivalent amounts of the elements in an evacuated sealed quartz tube did not produce stoichiometric compositions. (TAB U62-4-1: 47, Oct.1,1962).

We have investigated the thermoelectric properties of annealed single crystals of tellurium with different carrier concentrations (10¹⁴ to 10¹⁹ cm⁻³) over the temperature interval from 77 to 200 K and have determined the effective mass of the hole carriers on the basis of the data thus obtained.


The authors have measured the temperature variation of the electrical conductivity and thermo-emf in single crystals and polycrystals of Zn₄Sb₃ to determine their semiconducting properties. The Hall constant was determined at room temperature. Some of the samples investigated were subjected to zone recrystallization.


The thermoelectric power of several monovalent metals is positive in sign. It is the purpose of this letter to point out that the form of the electron-phonon interaction leads naturally to an anomalous positive contribution to the thermopower of all metals, and that the magnitude of this contribution depends strongly on the topology of the Fermi surface.


Fourteen sample compositions, representing combinations of As2Te3 and T12Se with Sb2Te3, Bi2Te3, or Sb2Se3, were prepared and tested. A number of the samples were amorphous while others were diphasal including both amorphous and crystalline phases. The material parameters were structure dependent with room temperature parameters ranging from $7.2 \times 10^{-4}$ to $1.8 \times 10^{-3} \Omega$-cm in resistivity, $3.1-1040 \mu V/K$ in Seebeck coefficient magnitude, and $3.6-19.0 \ mW/cm-deg$ in thermal conductivity.


In French. The low temperature anomalies of the resistivity, the electrical and thermal magnetoresistance, the Hall effect, the thermoelectric power and the specific heats in dilute alloys of transition elements in normal metals are reviewed. Particular the thermoelectric power may become larger than in the pure metals by several order of magnitude. The specific heat anomalies display the magnetic entropy due to the spin of the solutes. A tentative comparison between theory and experiment is presented.


Properties required for a compound to form useful thermoelectric materials are described. Uranium compounds which might have these properties are reviewed. Several of these compounds were prepared and fabricated into compacts. The apparatus used for hot pressing, and for the measurement of thermoelectric power, electrical conductivity, and thermal conductivity, is described. Detailed attention is given to the properties of the nitrides.


Potential thermoelectric materials investigated were: USx, USEy, UTez, and some ternary combinations of U with S, Se, and Te. Procedures were developed for preparation of the various compounds, fabrication of geometrically regular samples, and determination of the thermoelectric properties of these samples as a function of temperature. Uranium-sulfur and uranium-selenium binary compounds, and uranium-sulfur-tellurium ternary compositions were found to offer considerable promise as good thermoelectric materials. The uranium-selenium group probably has the highest range of useful operating temperatures. (Nuclear Sci. Abs., 17:14856, May 15, 1963).


Semimetals, which contain equal numbers of electrons and holes, have recently been returned to the list of optimum thermoelectric materials. Values of the figure of merit as high as $6 \times 10^{-3}/K$ have been measured at low temperatures on single crystals of the semimetallic bismuth-antimony alloys. Most of the properties of these materials are very sensitive to an applied magnetic field. The figure of merit, for certain orientations and magnitudes of magnetic field, can be more than twice as large as the zero field value. Values of $Z$ up to $8.4 \times 10^{-3}/K$ have been measured in a field of 1000 gauss at 100 K. These results are discussed in terms of the cooperative behavior of equal numbers of high-mobility, anisotropic electrons and holes.


In Russian. A review. Theoretical and experimental data on the thermoelectric properties of metals and alloys are generalized. It is concluded that during the formation of solid solution in a binary system consisting of thermoelectrically negative metals, the dependence of the absolute thermo-e.m.f. on the composition is represented by a smooth curve with a minimum (Ag-Au). This shifts the point of the zero thermo-e.m.f. towards the right at a junction with transitional metals. During the formation of solid solution in a binary system consisting of thermoelectrically positive metals, the dependence of the thermo-e.m.f. on the composition changes along a smooth curve with a maximum (Pt-Pd). This shifts the point of the zero thermo-e.m.f. towards the right at a junction with Cu. The formation of solid solution in a
binary system consisting of metals with thermoelectrically different signs produce a decrease in the thermo-e.m.f. and accordingly produces a displacement of the point of the zero thermo-e.m.f. to the right at a junction with Cu. (USSR Abs., J. of Metallurgy, no.9/10(Part A):31,1961).


Thermal, X-ray-diffraction, microscope, and thermoelectric methods were used and the system Cu$_x$Ag$_{1-x}$InTe$_2$ was shown to be a continuous series of metastable solid solution at temperature 650°C, and to be unstable and supersaturated at 650°C, from which secondary phases, e.g. Ag$_2$Te and InTe, are precipitated. Annealing increases both thermoelectric power and resistivity, but the former increases faster than the latter. In some compounds e.g., if $x=2/3$, resistivity decreases with annealing time. (Met.Abs.,30:587-588, Apr.1963).

E. Design, Principles of

4851

Statistical analysis, primarily analysis of variance, was applied to evaluate several factors involved in the development of suitable fabrication and processing techniques for the production of lead telluride thermoelectric elements for the SNAP 10A energy conversion system. The analysis methods are described as to their application for determining the effects of various processing steps, establishing the value of individual operations, and evaluating the significance of test results. The elimination of unnecessary or detrimental processing steps was accomplished and the number of required tests was substantially reduced by application of these statistical methods to the SNAP 10A production development effort. (Nuclear Sci.Abs.,17:11314, Apr.15,1963).

F. Applications

4852

Thermoelectrics are introducing significant new trends in heating and cooling. These include infrared detection and cold-probe electronic measurements. Other devices in the field are shown and their effect on future products is predicted.

4853

Survey of the current status of thermoelectricity, and of its space applications. Developments in thermoelectric materials are discussed, and the characteristics of the most promising materials are outlined. It is shown that valid design concepts of thermoelectric converters are now available with (1) isotope or reactor heat sources, (2) unfocused solar energy, or focused energy from large or small collectors, and (3) either battery or thermal storage. In each case, the converter is shown to be lighter, less expensive, and of longer lasting reliability than other existing systems, but to have limitations in regard to size and efficiency. The use of thermoelectric units as heat pumps and refrigerators is discussed. (Intern.Aerospace Abs., 2:52-10786, Nov. 1962).

1. Power Generation

4854

The phenomenon of voltage generation by means of heat applied to junctions of different metals has been known for many years, and the advent of semiconductors which have properties superior to metals has given increased impetus to this field. Numerous practical applications have already developed and *still* others seem feasible. This note describes one such application of thermoelectric elements to provide a very low voltage direct-current supply.

4855

The object is to investigate the feasibility of utilizing wood, coal, charcoal, or other locally available fuel found in world-wide areas as a heat source, for a thermoelectric generator or small engine-driven generator capable of producing 150 watts of electric power.
DESIGN OF THERMOELECTRONIC 300-KW GENERATOR.
In Polish. Transl. in FTO-TT 02-1824, by Air Force Systems Command, Foreign Technology Division.

Manufacture of several types of thermo-electronic generators with power rating of 30 to 300 kw was proposed. It is contemplated to build first a 30-kw generator; other generators with a higher power rating will be built after a thorough testing of the prototype. Heat energy will be supplied by a small nuclear reactor.


This work is a review of the technical developments that have led from early semiconductor research to the emergence of the thermoelectric generator as a rapidly growing power source of high reliability.


The report covers the first phase of a program, the objective of which is the development of a self-contained thermoelectric power supply. The use of a radioactive source of heat incorporated in everyone of 36 thermoelectric components will be considered towards the end of the second phase. Only non-radioactive heat sources have been used during Phase I.


A proof-of-principle, thermoelectric device is described which is fueled with a high energy (1875 calories per gram) high density (1.8 grams per cubic centimeter) fuel slurry. Handling and storing the fuel for periods up to one year offered little difficulty; however, operating problems, such as fuel feed to the burner and ash removal from the burner, were not fully solved. Two fuel feed systems were designed and tested; a gravity drop system which is suited to low power output devices of up to 5 watt electrical output and a pressurized, continuous fuel feed system which is suited to devices about 5 watts electrical output.


The report describes the results of a study on the economic aspects of mixed fission product type generators, in which a cost comparison with a pure radioisotope-fueled thermoelectric generator of the SNAP 7 type is made. Cost of the radioisotope fuel, potting the fuel source, special materials of construction, biological shield materials and attendant fabrication and transportation costs are considered. In addition, problems involving the handling and emplacement of the larger size thermoelectric generators are discussed.


Details are presented of flat-plate solar-thermoelectric generator research results, and the concept operation discussed from a systems standpoint. System factors and potentials are estimated, assuming the concept to be developed to the point where operational feasibility is established. (Nuclear Sci.Abs., 17:9132, Mar. 31,1963).


A low power device, simulating a section from a megawatt output generator, has been built to test a new idea for the arrangement of thermoelements around a cylindrical pipe. The device uses bismuth telluride type thermoelements and operates between a condensing vapor source at 250°C and a sink of cooling water at about 20°C. The maximum measured efficiency was 2% at 13 watts output.


Design methods and performance data for heat rejection devices applicable to
thermoelectric generators; first one, wire-coiled extended surface, removes heat through natural convection mode; second one, transverse-finned surface, makes use of forced convection heat transfer for relatively large power output units. (Eng.Index, p.190, May 1963).


The design and performance capability of thermoelectric generators for the conversion of solar energy and relative system economics are the scope of this paper. A brief review of the equations and parameters of importance in predicting performance of a thermoelectric generator, and the status of materials for this mode of energy conversion are presented. As a best estimate at this time 7 to 10 cents per kwh for the cost of electrical energy from a solar-thermoelectric generator appears plausible in the size ranges discussed (50 to 1000 watts). With time, the efficiency of thermoelectric probability reduce the cost of electric power per kilo-watt hour further. However, even at the present cost range, solar-thermoelectric power generation appears attractive for many areas of the world. (Solar En., 7: 82, Apr.-June 1963).


Review is presented of a modular solar thermoelectric power supply system, which includes thermal energy storage and orientation devices. Incorporation of concepts outlined is expected to satisfy some long-life requirements of communication and weather satellites. A comparison of thermal storage with other systems for supplying continuous power is presented. (Nuclear Sci.Abs., 17:9128, Mar.31,1963).

Martin Marietta Co., Nuclear Division, Baltimore, Md.

Design, fabrication, and progress in achievement are reported for SNAP 7A,7B,7C, and 7D generators. 4867

Martin Marietta Corp., Nuclear Division, Baltimore, Md.

The objectives of the SNAP 7D program were to design, manufacture, test and deliver a thirty-watt electric generating system for a modified U.S. Navy NOMAD-class weather buoy to be stationed in the Gulf of Mexico. This report describes the sixty-watt strontium-90 thermoelectric generator, the relay panel, the batteries, and the installation of the system in a boat-type buoy.

Monsanto Research Corp., Dayton Laboratories, Dayton, Ohio.

The experimental model generator completed more than 800 hrs of operation of a substanstied performance test at a hot end temperature of 1200°C (+25, -0°C), cold end at about 714°C (+12,-0°C) in a vacuum of 10^-5 mm Hlg without degradation of its power producing characteristics. The test is continuing. Progress was made in efforts to improve the properties of high temperature n- and p-type thermoelectric materials needed to supplement p-type MCC 50, the thermoelectric material used in the experimental model generator now under test. Investigations were initiated to develop improved emissive cold-end radiator coatings and methods for fabricating MCC 50 thermoelectric modules. (Nuclear Sci.Abs., 17:8944, Mar.31,1963).


Thermoelectric power generators present one of the most promising technological developments today. Overall therm efficiencies of 2-3% exist using hydrocarbon fuels and 4-6 using radioisotope fuels at system specific power outputs of 4-8 watts per pound and costs of $50-$100 per watt. Thermoelectric material costs have dropped from $1500 to $100 per pound within the last three years and much lower costs are anticipated as material usage increases. Overall system operating thermal efficiencies of 14-18% at specific power outputs of 40-70 watts per pound of system are projected.

Against a background of several years of basic studies, and recent progress with available materials, emphasis shifts to the design of practical devices for space systems.


In order to make a study of the electron scattering mechanism in indium arsenide at T=77°K, one sample of the semiconductor with a current carrier concentration of 3×10^{16} cm^{-3} was used in a combined investigation of the following kinetic phenomena: 1) electrical conductivity, 2) Hall effect, 3) magnetoresistance, 4) thermal emf, 5) and 6) the two Nernst-Ettingshausen thermomagnetic effects. The heat conductivity and thermal emf were investigated over the temperature range from 2-5 to 100°K. A comparative study was made to find what role the geometric effect plays in the magnetoresistance and the magnetothermal emf.


In French. A method is proposed for directly converting thermal energy into mechanical energy by means of thermoelements. As an example, a simple device is described. The first experimental results show that this technique has many advantages in the case of low energies.


The objective of the program has been to improve the life-performance of thermoelectric generator modules by means of engineering development and evaluation in the areas of insulation, material processing, and contacting. This final report presents additional data primarily related to the continued testing of materials for use in power generator modules.


A constant speed drive mechanism has been incorporated into the collector concentrator and operates as planned. A ten-couple module has been extensively tested and the results indicate the feasibility model can produce 18.3 w. The waste heat radiator test rig is being assembled. Problem areas are still being encountered in the thermal energy storage system. A preliminary system design has been completed. A test specification is included. (TAB U62-4-6:30, Dec. 15, 1962).


A heat-exchanger has been assembled and tested to determine the performance of the waste heat radiator and to determine the heat losses from the thermoelectric power converter. A thermoelectric module efficiency tester was built and a typical section of thermopile was tested. The test results show that the power required by the thermocouples is 30% greater than anticipated. The power input is greater than anticipated since the efficiency of the couple is 15% lower and the power output is 13.9% greater than the calculated values. Delays are still being encountered in the thermal energy storage system. (TAB U63-1-6:10-11, Mar. 15, 1963).

2. Heat Pumps


Heat dissipation from microminiature components encapsulated or otherwise enclosed within microminiature systems can prove a difficult problem. Four suggested methods are considered but each has its limitations. The Peltier-junction refrigeration system is a classic heat-pump most compatible with microminiature
units; a microjunction comparable in size to a microtransistor will dissipate the heat from five such transistors. Typical constructions are described (usually semiconductors) and operating parameters, automatic control and most suitable materials are discussed, i.e. p-type Sb, Pb, Bi telluride; n-type Pb and Bi telluride. Cr-constantan Sb-Bi, Bi telluride thermocouples. Overall electrical efficiency is increased by obtaining the necessary current from Seebeck generators positioned in the hotter regions of the equipment. (Elec. Eng.Abs., 66:3842, Apr.1963).

4877
American-Standard Corp., Union, N.J.

The design details of a 6000 Btu/hr thermoelectric air conditioner are presented. The performance specifications are summarized and the design calculations are also outlined. At design operating conditions, this air conditioner should produce 6000 Btu/hr of cooling with an over-all coefficient of performance of 0.44. The unit is equipped with a number of small blowers which circulate air over the fins attached to the cold thermoelectric junctions and a second set of blowers which circulate air over the fins attached to the hot thermoelectric junctions. The air conditioner weighs approximately 85 pounds and is designed to fit conveniently in the wall of the enclosure to be cooled. (TAB U63-2-3:43, May 1,1963).

4878

A transistor circuit to control the operation of a thermoelectric "cold" stimulator is described. Rectangular current pulses are available of amplitude 0-10A, duration 1-4 sec., either singly, or repetitively at pulse intervals 5-15 sec. (Elec.Eng.Abs., 66:5001, May 1963).

4879

The advantages and applications of thermoelectric cooling devices are discussed.

4880

The Peltier effect has become a practicable method of small-scale refrigeration. This is a consequence of the development of semiconductors, and very compact units are now available; one of volume about 0.03 cubic inch will give a heat transference of about 0.1 calorie per second.

4881
Sendlors Corp., Research Laboratories Division, Southfield, Mich.

This report describes the development of a thermoelectric-cooled, mirror-type dewpoint hygrometer for use in measuring dewpoint in the range of -80°C to -50°C in altitudes between 100K feet and sea level.

4882

This note describes a method of maintaining an ice point to provide a 0°C reference temperature for a thermocouple junction. Two thermoelectric refrigerating elements are used to cool a small container of water until it is partially frozen. The volume change of the water on freezing is used to control the power to the cooling elements so that the volume of ice remains constant.

4883

The design of a microscope stage cooled by a thermoelectric device is discussed. The temperature was stabilized near 0°C using the latent heat of fusion of ice.

4884

The advantages of thermoelectric refrigeration, some of its possible applications and its principles of operation are briefly presented. The current state of the art in thermoelectric materials is discussed. The design problems in developing thermoelectric devices and some of the current techniques used to solve them are reviewed. Some information is provided on devices that have been built for the U.S. Navy and for commercial application.

4885
Goldsmid, H.J. THERMOELECTRIC AND THERMO-

Only recently materials have been developed which have enabled the Peltier effect to be of practical use. The article discusses the requirements and considers the possibilities of another effect - the little-known Ettingshausen effect.

4886

Some applications of thermoelectric cooling are discussed and then the possibilities of thermomagnetic cooling are considered. This form of cooling depends on the Ettingshausen effect and has certain advantages, but is most effective at very low temperatures.

4887

This temperature control method is extremely flexible because it can be used in systems that have to operate in various ambient temperatures and deliver various controlled temperatures. It can provide temperature control requiring only cooling, only heating, or both cooling and heating. This article deals with devices that provide both heating and cooling because most applications require that ability and also because such devices most fully illustrate the principles involved.

4888

A brief description plus illustration is given for thermoelectric spot coolers which let four fluorescent tubes do the work of seven. By chilling each tube to maintain mercury-vapor pressure at an optimum value, the coolers increase lamp output by 72 per cent.

4889

Several thermoelectric devices to provide refrigeration for air conditioning and food storage aboard submarines have been developed under US Navy program by different contractors; these include 1/6-ton cooling capacity chilled water to seawater units, 1-ton air to fresh water unit, and refrigerated food units; all use bismuth telluride as thermoelectric material. (Eng.Index, p.167, Jul. 1963).

4890

In German. Knowledge gained of semiconducting compounds in recent years has made technical application of the Peltier effect possible. The theory of thermoelectric refrigeration, the present state of the art concerning semiconducting Peltier junctions and the performance of refrigeration devices developed therefrom are surveyed. The performance is also compared with that of conventional absorber and compression type refrigerating devices. (Elec. Eng. Abs., 66:540, Jan. 1963).

4891

The combination of a thermoelectric refrigerator and thermoelectric generator in one installation to generate cold without external sources of electric power is discussed. The possibility of creating a refrigerator for quick cooling and freezing of water and operating with the heat from an ordinary gas burner was investigated. Such a refrigerator consists of a cylindrical copper or aluminum tank at the bottom of which are installed semiconductor plates forming the individual elements of the electronic refrigerator. It was found that the refrigerating capacity of the device is sufficient for cooling by AT = 20° and freezing of approximately 0.70 kg of water per hour. (Res. Devlpmt. Abs., 2:356, Apr.-June 1962).

4892

A new and unique solution to the cooling problem lies in the application of thermoelectric cooling. Thermoelectricity derives its heat pumping capability from the difference in the electron energy level in the p and n-type materials that are used to construct the thermocouple. As an electron traverses the p-n junctions, heat is absorbed from the load and evolved at the heat sink. Therefore, to utilize this system, the designer need only to control the magnitude of the thermoelectric device current to achieve cooling action.

The differential equations which describe the steady state temperature distribution in a thermoelement with constant properties and with convective heat transfer from its longitudinal surface are presented and solved analytically. The solutions are applied to a single-element thermoelectric heat pump to determine the effect of surface heat transfer upon the maximum temperature difference, the maximum heat pumping, and the maximum coefficient of performance. The results show that each of these three performance criteria can be increased through the use of surface heat transfer.


In German. The refrigerating capacity of a single element is discussed. A survey is given on the obtainable efficiencies on the basis of which interesting performance conditions and refrigerating capacities are described. Questions concerning the determination of element dimensions are answered. (Appl. Mech. Rev., 16:553, July 1963).


Thermoelectric and ultrasonic cooling techniques were investigated along with cooling by immersion in a cryogenic fluid. The purpose of this effort was to determine the applicability of these techniques for the cooling of electronic equipment. Experimental results are evaluated, a comparison of these techniques has been included, and recommendations concerning the application of each technique are presented.


This report covers internal work on the use of a specific Peltier temperature control device, called a "thermoelectric thermal barrier", to protect heat-sensitive electronic circuit elements from closely associated heat-producing elements in a microelectronic assembly. Test results on a simulated binary divider micro-module indicate the feasibility of the thermoelectric thermal barrier approach.


A computer program was established to investigate various design parameters of thermoelectric coolers. A discussion of this program and the results obtained for various designs are presented.


An approximate design procedure on a thermoelectric single couple is presented using average values of material parameters. It is shown that a thermoelectric chamber is a low voltage, high current and low ripple device. A-c to d-c power conversion using fundamental silicon rectifier circuits is discussed. Theoretical operation of a static d-c to d-c power converter is described. Emphasis is placed on circuit losses and important transistor ratings. It is shown that a simulation of the principal elements in a thermoelectric chamber temperature control system can be made and evaluated on a analog computer. Experimental investigations on best pumping performance and temperature control are given for several chamber designs. An investigation on chamber design criteria is presented with respect to various parameters.


Modified ovens have been installed in one AN/URQ-9 Frequency Standard. The performance of the modified ovens is such that in an ambient temperature from 0°C to 45°C the crystal is maintained at a temperature from 20°C to 28°C regulated to accuracy of at least ±0.01°C. (TAB U62-4-6:40, Dec. 15, 1962).
One important characteristic in the consideration of a heat pump is its coefficient of performance, defined as the ratio of the heat removed by the refrigerant to the work performed on the refrigerant. In the case of a thermoelectric device, the refrigerant is the electrical current that flows through the circuit. The thermoelectric power involves the thermal and electrical conductivities of the materials, and the operating temperatures of the junctions are therefore important in determining the dynamic behavior and overall efficiency of the refrigerator.

3. Thermocouples

4901

The thermoelectric output versus temperature of a W/W - 26Re thermocouple was measured to 5800°F. Thermoelectric sensitivity was relatively high over the entire temperature range. Thermoelectric output on new thermocouple systems versus temperature was also measured with respect to W - 26Re commercial wire for Re-Re6W, Re-9W, Re-12W, Re-15W, Re-18W, Re-20W, Re-30W, Re-40W, Re-50W, and Re-100W alloys. Of the alloys studied, Re-10Ru and Re-12W show the greatest potential for high-temperature thermocouple application.

4902

The authors develop the classical theory of transport phenomena, as applied to thermocouples, using the Boltzmann transport equation.

4903

An experiment is described in which the response of a thermocouple to an instantaneous change of temperature was measured directly. A simple circuit is described to permit observation of changes occurring within a few ms with a mechanically robust junction. (Instr. Abs.,38:489-490, Dec.1961).
investigate the drop of radiation balance in the top ice layers of a glacier. The radiation sensitive area of the instrument has a diameter of no more than 7.5 mm and allows nearly undisturbed measurement of the radiation balance. The data obtained permit a direct calculation of the energy transformations taking place in these layers. Calculations are given of the optimum wire size for the thermoelectric elements between the two receiver plates. Measurements were made in pure glacier ice. The average extinction coefficient in the layers from 0 to 20 cm depth was found to be 0.14 cm⁻¹. Below that depth the extinction coefficient assumes a constant value of 0.018 cm⁻¹. Half of the incident energy is absorbed in the first 1 or 2 cm. At a depth of 10 cm only 10 percent of the energy remains. Thus the radiation balance decreases somewhat more sharply than the short wave radiation measured with a spherical receiver.

In French. The microcalorimeter fitted with multiple thermocouples is calibrated by means of the Peltier effect. In order to calculate the heat flux it is necessary that all the thermocouples be used alternately as generators and detectors. The appropriate circuit arrangements are described. (Phys.Abs.,66:3916, Mar.1963).

A rotatable metal-block-calorimeter with thermoelectrical measurement of temperature is described. The platinum-lined combustion block is made of electrolytic copper. The zero-blocks, set up symmetrically on both sides of it, are of pure aluminum. Eight thermo-piles, with 50 elements each, are used for measuring. The small combustion-shell, also of platinum, is freely suspended so that its contents are never spilled during rotation. The whole calorimeter, is mounted on bearings, and is housed in a high-vacuum container, which can be evacuated down to a pressure of 10⁻⁵ mm Hg. A multi-jacket thermostat is used for thermal isolation. In the outer jacket the temperature constancy is better than 10⁻⁵°C. The sensitivity of the calorimeter has been tested by the burning of some typical substances.

The Model C Hermach-Engelhard standard is a thermoelectric transfer instrument utilizing a thermal converter as a transfer element. The instrument is capable of measuring dc and ac voltage over the range 0.2 to 1500 volts, and current over the range 5 ma to 25 amperes. The instrument's accuracy of better than 0.05%, without correction factors, can be certified over the frequency range 5 cps to 50 kc/s, on voltage ranges to 600 volts and current ranges to 5 amperes. All higher ranges possess this certified accuracy over the frequency range 5 cps to 20 kc/s; dc currents and voltages can be measured with the same accuracy over the entire ranges of the instrument.


A miniature portable thermoelectric anemometer AT-1 for measuring air speeds over a wide range from 0.001 to 20 m/sec. has been developed.


The paper analyzes several common satellite component control problems and establishes the usefulness of thermoelectric control. In addition, the experiments carried out to demonstrate the feasibility of using thermoelectric modules as a thermal switch are discussed in detail.


The author, in an earlier paper, analyzed a Nernst effect generator by the usual thermodynamic methods and found that a bound of unity arises on the dimensionless quantity of where o is given as the square of the product of the Nernst coefficient and magnetic field divided by the thermal conductivity and electrical resistivity. By application of the appropriate equations of semiconductor theory this bound is shown to be justified for four limiting cases: Weak magnetic fields considering both extrinsic and intrinsic materials, and strong magnetic fields considering both extrinsic and intrinsic materials.


A large figure of merit, for a device operating in the transverse mode, is obtained in an intrinsic system which has large and approximately equal electron and hole mobilities.


A calculation is made of the anisotropy of the even effects in crystals with orthorhombic and rhombohedral lattices. It is shown that the anisotropy in the longitudinal Nernst-Ettinghausen thermomagnetic effect in a magnetic substance, in the temperature range below its low-temperature transformation, is described by the equation obtained for the anisotropy of the even effects in crystals with orthorhombic symmetry.
The thermomagnetic and galvanomagnetic effects present some new potentialities in the field of direct conversion of heat to electrical power. A device referred to as the "Nernst generator" operating on the Nernst and Ettingshausen effects is studied. The thermodynamic performance of the device is analyzed. The results show that there exists a dimensionless grouping of the properties of the material, called the "thermomagnetic number," which governs the suitability of a material for this application. The present-day knowledge of the properties of the material, relevant to this application, are discussed. From this discussion, it appears that, contrary to the case in thermoelectric applications, intrinsic semiconductors, within a certain range of temperature, are more promising than extrinsic semiconductors. This would permit the device to operate at higher temperatures. (Nuclear Sci.Abs., 17:9101, Mar.31, 1963).

The Nernst generator looks fairly promising for converting heat directly to electric power. Basically a solid-state MID generator, it operates on the principle that a thermal current through a conducting block in a uniform magnetic field produces a potential across the block's faces. The better the thermomagnetic properties of the block, the more efficient the conversion.

The utilization of the Nernst and Ettingshausen (NE) effects in direct energy conversion is discussed. The operation of generators and refrigerators is described qualitatively. Equations specifying their operating characteristics are cited and compared with those pertaining to the usual thermoelectric devices. Criteria are developed which show the conditions that one should attempt to meet in order to attain the most efficient energy conversion with NE generators and refrigerators. Bismuth and Bi-Sb alloys show promise as materials for these energy converters, since figures of merit of 0.4 have been observed. It is stressed that the search for new materials should not be limited to substances with low thermal conductivities or equal hole and electron mobilities.
and the Seebeck coefficient have been measured on Te- and Se-doped GaSb between 60° and 800°K. The two minima conduction band model, as applied to the present group of measurements, provides a qualitative description of conditions under which certain scattering mechanisms will dominate the transport phenomena.

4925

Formulas for efficiency and coefficient of performance are derived for devices based on the Nernst and Ettingshausen effects. The equations reduce to those of Harman and Honig in the limits of small figure of merit and refrigerator current, but they do not approach the Carnot limits. To obtain a better device theory, one must solve a two-dimensional partial differential equation in which the current density is allowed to vary with position. A crude maximization procedure for the figure of merit is shown for a one-band nondegenerate semiconductor in a weak magnetic field. Experimental data indicate that HgCd1-x Te alloys are perhaps the best materials for such devices at present.

III. THERMIONIC EMISSION
A. General Information

4926

This report presents the results of the past year's work in a continuing program to investigate basic processes in thermionic energy conversion important to a thermionic nuclear power plant for naval applications. The subjects discussed in the present report are: Statistical Mechanics of Cesium Adsorption; Space Charge Analysis for Low Pressure Thermionic Diodes; Emission requirements for Removal of Space Charge Barriers; Ignition Mode of Thermionic Converters; Interpretation of Volt-Ampere Characteristics; Vaporization and Deposition at Cesium Covered Surfaces; and Cesium Purification.

4927

The effect of directed ion formation was studied depending on which of the 3 filament sources the evaporation took place. The original cause for the generation of smaller or greater ion currents seems to be the evaporation of the sample from different metallic surfaces. When the surface of a W vaporizer was increased by placing on it some W powder, the intensity of the ion beam for samples of the same weight increased many times. The mechanism of the directed ion formation is discussed and the reasons for the differences between ion currents relative to the material of the vaporizer surface are considered. (Chem. Abs., 58:6288, Apr. 1, 1963).

4928

The detection and measurement of thermoelectron currents from W and a Cu-Ni alloy are described. The metal whose thermoemission current is to be measured is used as the cathode in a G-M tube, and Ar and Ar-ethanol mixtures are used as the filler gases. Voltage pulses are applied to the cathodes, which are at 500 to 1100°K, and the currents are measured as functions of the cathode temperature and the pulse duration. (Nuclear Sci. Abs., 17:3583, Feb. 15, 1963).

4929

The program includes work on materials development, converter development, and reactor and system analysis.

4930

Investigation concerns the use of photon processes for thermionic converters. The program objective is to determine the feasibility of enhancing the performance of cesium vapor thermionic converters at low temperatures, i.e., 1200 C, through photon processes. These photon processes are expected to increase the power output of a cesium converter by reducing the drop through the converter under load.
conditions by (1) increasing the conductivity of the positive column, (2) altering the potential distribution in the inter-electrode space, or (3) a combination of such effects. There is, in addition to the effect on full load operation, the use of photons to aid in establishing the discharge by generating enough ion pairs to accomplish gas tube breakdown or arc initiation, in the usual sense. (TAB U63-1-5:84, Mar.1,1963).

4931
General Electric Co., Syracuse, N.Y.

A new static heat-to-electricity conversion principle is described which attempts to duplicate in the solid state at a lower temperature the high impedance performance of a vacuum thermionic converter. The basic arrangement is a multilayer structure of thin film semiconductors or insulators perpendicular to the heat flow, separated by thin layers of metals. The optimization of the transverse mean free path of the charge carriers, film thickness, contact potentials and other parameters is discussed. An outline of the exploratory experimental study of this new concept and some practical details on film production and measurements are given. (TAB U63-1-4:46, Feb.15,1963).

4932
General Motors Corp., Allison Division, Indianapolis, Ind.

Theoretical work is reported to describe a model of a capillary thermionic emitter in which the neutral cesium density varies from some high value at the entrance to some low value at the exit. As a consequence of this model, the plasma density, the sheath potential, and the sheath thickness vary along the capillary. From this model, electron emission is predicted and compared with experimental results obtained on a monocapillary structure. (TAB U62-4:6:109, Dec.15,1962).

4933
General Motors Corp., Allison Division, Indianapolis, Ind.

Theoretical work is reported on a random current model of the capillary emitter - in this model the ion and electron emission currents are dependent upon the atom density at the capillary exit, and the emitter temperature. A solution of the cesium flow through a multicapillary converter was obtained in order to estimate the interelectrode pressure. Experimental data on three multicapillary converters are reviewed. (Nuclear Sci. Abs.,17:16773, May 31,1963).

4934
INVESTIGATIONS ON THE DIRECT CONVERSION OF NUCLEAR FISSION ENERGY TO ELECTRICAL ENERGY IN A PLASMA DIODE, February 1 - October 31,1962, by F.E. Jamerson, and others. 121p., Oct.31,1962. (Annual Rept.) (Contract Nonr 3109(00)).

Results of experimental and theoretical investigations are presented on the use of a nuclear generated plasma in a noble gas plasma diode thermionic converter. Related programs of emitter materials development and plasma measurements are described in individual reports.

4935

Volt-ampere curves have been obtained for systematic variations of emitter, collector, and cesium reservoir temperatures, with electrode spacings ranging from a few to many mean free paths, and with space charge conditions varying from electron-rich to ion-rich. Several discontinuities in slope were observed in the reverse current portion of the curves and these have tentatively been identified with volume ionization of atoms in both the ground and excited states. Similar processes may be important for obtaining the ignited mode. The methods used to measure static and dynamic volt-ampere curves are described. The use of a controlled-current load has yielded a "negative resistance" region in the curves which show the ignited mode. The curves obtained with poor current-control do not show this phenomenon. Extinction is considered from the standpoint of Kaufmann's criterion for stability.
Thermionic emission of electrons at very high emission densities was observed from a tungsten cathode when the surface was impulse-heated with a sharply focused laser light beam.


The materials problems most likely to hinder rapid development of a feasible power producing in-pile thermionic direct conversion diode are reviewed. A research program is suggested which should provide answers to these problems.


In German. Thermionic converter for direct generation of electricity from gas; principle of operation of thermionic converter; converter performing under vacuum; cesium filled converter; design of gas heated converter, combustion, heat exchange, and vacuum chamber. (Eng.Index, p.55, May 1963).


This paper surveys the state of thermionic converters as of mid-1961. These devices convert heat energy into electrical energy by utilizing the thermionic emission of electrons. In the last five years the power output and efficiency of such devices have reached around 5 watt/cm² at 15% efficiency.


Thermionic converter operation has previously been observed to occur with emitter temperatures and work functions too low for surface ionization. In addition, discontinuities and quasi stable operation were observed. A qualitative identification of this type of operation with the low voltage arc is made.

Analysis of the arc requires solution to the three fundamental problems of ionization mechanism, thermalization, and energy balance. It is shown that a solution for the first presents an apparent violation of the third. Analysis of thermalization indicates that processes more rapid than the usual collective interaction must occur. In particular, Maxwellian electron energy distribution close to the collector, or the "Langmuir Paradox", indicates the need for an oscillatory interaction mechanism. A brief discussion of possible arc models is given together with a review of techniques for obtaining the temperatures and densities within the arc plasma.


The basic theory of the thermionic converter is reviewed. Various methods of reducing the space charge limitation of current in a thermionic converter are discussed. In vacuum converters, the effect of space charge can be reduced by very close spacing or by the use of a crossed electric and magnetic field (the magnetic triode). Space charge can also be neutralized by introducing positive ions into the converter. In the cesium diode and triode, the plasmatron converter, and the pulsed diode, positive ions are supplied by ionization of a low pressure gas. Solid materials which emit positive ions when heated are also being investigated as a source of positive ions for space charge neutralization. The electrical and mechanical requirements for the emitter, collector and auxiliary electrode materials are discussed, as well as the problems related to insulators, seals, and electrical leads. The materials problems involved in using the thermionic converter with a nuclear reactor or a combustion chamber as the heat source are mentioned. The nuclear-heated application requires fissionable fuels and reactor structural materials that will withstand high temperatures and radiation damage. The combustion heated thermionic system requires materials with a reasonable lifetime when subject to corrosion and erosion by hot gases. Both applications require materials that are compatible with and can be joined to the electron emitters and insulators of the converter cells. (Nuclear Sci.Abs.,17:6553, Mar.15,1963).
Emitter activity and patchiness can be assessed from shot noise response curves of shot noise voltage versus emitter temperature, and vapor pressure. Specifically the characteristics: (a) temperature and pressure at which the noise sharply increases; (b) the rate of change in the slope of the curve in the transition region between space charge and temperature limited modes; (c) the level of space charge limited noise; can give indications of activity and patchiness at different times of emitter life. Using these characteristics shot noise can be used as a stethoscope to listen and predict trends in emission capabilities as a function of emitter lifetime before the effects are recognized in the output power. Appropriate shot noise sensing can be used as a reliability or quality indicator for electron emission in thermionic converters.


Due to the inherent high power-to-weight ratio of a thermionic diode, development of flame-heated diodes is being pursued for application to small, lightweight, silent power sources. To demonstrate that power could be obtained from a flame-heated cesium-vapor diode, a furnace was built using surface combustion in a bed of zirconia chips to heat a molybdenum emitter to 1500°C. The exterior of the emitter was coated with Durak-R, a protective layer of molybdenum disilicide, and in addition, a wafer of silicon carbide was used as a barrier between the flame and the coated molybdenum. Although the overall heating efficiency of the above externally heated diode and furnace was found to be low, it is shown that the heating efficiency can be improved considerably by using an internally heated diode. Some successful experiments of burners designed to fit inside a large thermionic diode are described. A prototype internally heated thermionic diode using a 1 in. ID molybdenum thimble with an 34 cm² emitter area was constructed and tested using electrical heating. Pertinent details of its construction and operation are described. In general, its performance was quite similar to that of cylindrical diodes, with an observed 8 per cent conversion efficiency at a 1540°C emitter temperature. Plans for the future development of the flame-heated diode concept are briefly described.


Results are reported on a study of the rate of attack by cesium vapor on a number of ceramic, metallic and metal-ceramic seal materials considered for possible use in the construction of cesium vapor thermionic converters. The main objectives in this study were twofold: (1) to obtain data on which to select attack resistant materials for use in current thermionic converter work, (2) to determine where concerted effort was needed and should be placed in more extensive attack rate experiments to follow.


This paper discusses the process of chemical regeneration of hot metallic...
surfaces, which may find application in very high temperature thermionic devices. In the process, gaseous materials such as chlorine form compounds with the metal departing from the hot emitter surface. The metallic compounds return the metal to the emitter surface where it is redeposited. The migration of electrons and ions in a scattering gas is described in terms of a recombination coefficient, \( \gamma \).


Material compatibility as related to the "marriage" of reactor fuels to refractory metal thermionic emitters is under investigation. Four fuel materials, UC, UC\(_2\), UC-ZrC, and UO\(_2\), are studied in combination with tungsten, molybdenum, tantalum, and niobium over the temperature range 1200°-2000°C. A technique has been developed for simultaneously studying the interdiffusion between a given uranium-bearing material and each of the four refractory metals.


Contents: Current-voltage characteristics of materials in variable spacing cells; Measurements in plasma anode discharge cell; Electron and ion emission from cesium coated refractory metals in electric fields; Electron reflection measurements; Rubidium vapor thermal conductivity. (TAB U63-1-3:20, Feb.1,1963).


Radio-frequency oscillations are observed in alkali vapor-filled thermionic diodes at low vapor pressure. A review of the experimental phenomena and attempts at quantitative theoretical understanding is given. Possible applications are for energy conversion and as a diagnostic tool.

B. Theory


One of the primary reasons for the failure of thermionic converters to attain their ultimate theoretical performance is electron transport effects occurring in the interelectrode spacing. Two major types of transport effects, electron scattering and electric space charge, are discussed and theoretical results compared with experimental data. The uniform plasma theory is reviewed and experimental data show that for a monocrystal emitter this theory is consistent with the energy equation. Space charge neutralization is discussed. Both surface ionization and volume diffusion of electrons and ions in a neutral gas. Adv. Energy Convers., 2:395-403, July-Sept. 1962.

The migration of electrons and ions in a scattering gas is described in terms of the diffusion approximation to transport theory. A discussion of the range of validity of the diffusion theory and the conditions required for constant transport coefficients is presented. The theory is used to analyse a planar high pressure thermionic converter. It is assumed that the electrons and ions originate from the surface of electrodes as a result of thermionic emission and surface ionization respectively.
ionization are considered. Experimental results indicate that surface ionization is not as effective as would be expected by theory. This fact is responsible for the discrepancy between theoretically expected and experimentally obtained performance of converters. Under the conditions where surface ionization is inadequate for space charge neutralization, volume ionization can provide the necessary ions. Volume ionization, however, is achieved at the expense of the output power of the converter.

1. Emission Phenomena

4954
Aerospace Corp., El Segundo, Calif.

A theoretical model of a cesium thermionic converter operating in the ignited mode, is investigated in order to determine the possible role of Schottky emission (produced by the accelerating field of an ion-rich emitter sheath) in causing the high currents observed in that mode. The electric field intensity adjacent to the emitter is determined as a function of plasma density, electron temperature, and emitter sheath potential by integration of Poisson's equation between sheath edge and emitter. The integration employs expressions for charged particle densities derived from the Bohm analysis of a stable positive ion sheath. The interelectrode plasma is considered to be uniform. Simultaneous solution of relationships expressing (1) continuity of electron flow, (2) conservation of energy for electrons, and (3) balance of ion production and loss mechanisms in the plasma with the sheath field relationship, permits generation of current-voltage characteristics. It is concluded that the Schottky effect contributes substantially to the production of observed high currents. (Astron. Info. Abs., 6:61,566, Nov. 1962).

4955

Values for the work functions of thermionic emitter surfaces composed of alkaline earth oxides have been approximated by means of a closed energy balance cycle which is a modification of the Born-Haber Method ordinarily used to estimate lattice energies or electron affinities. Comparison of calculated surface potentials with reported work functions for alkaline earth oxides disclosed reasonable agreement. The modified Born-Haber cycle includes, among other terms, the lattice energy, the heat of sublimation, and the molecular electron affinity of the gaseous, neutral, diatomic molecules under consideration. Justification for the incorporation of these quantities into the energy balance, together with the general implications of this method of estimating work functions, is discussed.

4956

Experiments are carried out to explain the occurrence of Joshi Effect in a "free electron" gas such as argon. The influence of increased thermionic emission on the discharge current is also studied.

4957
DEVELOPMENT OF BARIUM OXIDE-URANIUM OXIDE - TUNGSTEN AND BARIUM OXIDE - URANIUM OXIDE - RHENIUM EMITTERS FOR USE IN NUCLEAR HEATED THERMIONIC CONVERTERS, June 1, 1962 - June 30, 1963, by F.F. Gifford and R.F. Hill. 78p., July 1, 1963. (Annual Rept.) (Contract Nm 3870(00)).

The results of experimental and theoretical investigations that were conducted on various BaO-UO2 emitter materials are presented. X-ray analysis, evaporation rate studies, thermochemical calculations, electron emission studies and thermionic emission microscope examinations are discussed in detail. The results indicate that emitters containing 60 m/o BaO and 40 m/o UO2 dispersed in a matrix of either tungsten or rhenium are comparable to the commercial dispenser type emitters that employ tribarium aluminate impregnated in tungsten. The use of UO2 in the emitter materials produced an emitter with a self contained heat source when operated in a nuclear environment.

4958

This paper describes emission and discharge measurements made on a Cs-Ta emitter in a tube with parallel electrode geometry and with an adjustable emitter-collector spacing. Emission results indicated that this particular Ta-Cs emitter surface has an emission capability greater than that reported by Taylor and Langmuir for Cs-W, while the emission maxima are shifted to lower temperatures. This increase in emission over that usually reported for Cs-Ta is believed due to a preferred orientation of the Ta surface. The large enhancement of the emission during the
discharge is believed due to the lowering of the work function by the effective increase in the adsorption of Cs which is due to the increased arrival rate caused by the retarding field for ions. This mechanism is probable in the region where the surface ionization is expected. The discharge studies involve the measurement of the breakdown and maintenance potentials of the hot cathode arc discharge for various emitter-collector spacings, emitter temperatures and Cs pressures. Corrections for the contact potential and sheath potentials are applied to the experimental data. For a pressure the order of 1 mm, and high emitter temperatures, the results indicate that the magnitude of the emitter sheath potential is close to the first resonance level of Cs. This strongly suggests a multi-step process.


Activation effects in the thermionic emission of various uranium compounds appear to be caused by the formation of free uranium on the surface of the emitter.


A review of the factors affecting the operation of emitters in thermionic energy-converters. It is considered that refractory metals using adsorbed Cs offer considerable advantages. (Met.Abs., 30:586, April 1963).


An analysis of the cesium vapor arc discharge is presented. It is assumed that the discharge operates in the ball-of-fire mode, that cumulative ionization via the two resonance excited states is the predominant ionization mechanism, and that trapping in the plasma of the resonance radiation results in a long effective lifetime of the excited states. A volt-ampere characteristic is derived for the cesium arc and the results are applied to the thermionic energy converter. Good qualitative agreement is obtained between theory and experiment.


Thermal activation, the thermionic and secondary emission properties, and the poisoning of cathodes of thorium and yttrium oxides on niobium and rhenium substrates has been investigated; the data are compared with the data obtained by using cathodes on tantalum and molybdenum substrates.

Los Alamos Scientific Laboratory, N.Mexico.


Thermionic emission constants of UC, UMoC2, Pu203, PuO2 + PuC, UWC2, and NpC3 were measured. A cylindrical diode geometry was used. The emitter consisted of a 0.030-in. W wire coated electrophoretically with the desired substance. (Nuclear Sci., 17: 16783, May 31, 1963).


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This article gives the work functions of $\text{HfC, HfC}_2$, $\text{VC}$ and $(\text{UC})_4(\text{ZrC})_4$, calculated from the total current extrapolated to zero field. We have shown how the work function of these substances changes with increase in the temperature. For $\text{HfB}_2$ and $\text{HfC}$ we give data for emission in the presence of cesium.


The problem of space-charge potential distribution in a diode is considered in the case where limitations are counteracted by the introduction of ions at the emitter. The no-collision approximation is used in which inelastic and short-range elastic collisions are neglected and each particle interacts with the Coulomb field of all the other particles. The electrostatic potential is determined, in a self-consistent manner, from Poisson's equation. The equations are simplified by transforming to reduced variables in a manner described by Langmuir and others. There are eight important cases, each describing a different type of spatial variation of potential in the emitter-collector inter-space. Numerical solutions are presented showing the character of these potential shapes.


The space-charge potential theory in low-pressure thermionic converters is extended to cover emission of electrons at the anode as well as both ion and electron production at the cathode. The contribution of each of these sources to the charge density is expressed as a function of potential for each of the ten important cases. The first integrations of Poisson's equation are given for each of the cases. Previous analytical work by P.L. Auer and by the author reporting first integrations of Poisson's equation without anode emission appears as a special case in this paper. In addition, in each of the ten first-order differential equations there appears a term giving the contribution of anode emission.

4968 Minnesota University, Institute of Technology, Minneapolis, Minn. STUDIES OF PRIMARY ELECTRON SOURCES, December 1,1961 - March 1,1962, by D.E. Anderson. 68p.,illus., Sept.1962.


Measurements of electron emission from $\text{ZrC}$, both under high vacuum conditions and in an atmosphere of caesium vapour, are presented. Under vacuum conditions emission constants were determined.


Measurements are presented which demonstrate that the electron emission of molybdenum in cesium vapor is greatly enhanced by the addition of cesium fluoride. This enhancement amounts to a factor of about 340 at the maxima of the respective Langmuir S-curves for a cesium pressure of $10^{-2}$ mm Hg. (SR 4) (AFCR-L-63-5) (Contract AF 19 (604)-8381).
Emission processes establish the upper limit of the performance obtainable in the thermionic converter. This paper briefly introduces the basic factors which must be considered to achieve this limit and outlines recent developments in the related technology. The basic elements of thermal excitation common to these processes are outlined and the results are used to illustrate the interdependence of the atom, electron and ion emission processes.


Emission processes establish the upper limit of the performance obtainable in the thermionic converter. This paper briefly introduces the basic factors which must be considered to achieve this limit and outlines recent developments in the related technology. The basic elements of thermal excitation common to these processes are outlined and the results are used to illustrate the interdependence of the atom, electron and ion emission processes.


Investigation of the energy spectra of field-emitted electrons and thermionic electrons in the case of tungsten has demonstrated the suitability of the experimental apparatus employed for investigating the energy spectra of field-emitted electrons in the case of semiconductors. It is shown that increase in the internal field in the emitter leads to heating of the electron gas, and carrier generation commences when the total width of the field-emitted energy spectrum approximately coincides with the energy gap in CdS. Increase in the temperature of the emitter leads to a broadening of the energy spectrum and to a shift of the distribution maximum in the direction of higher energy electrons.


The thermoelectric power of barium oxide, strontium oxide and mixed barium and strontium oxides on platinum cores has been investigated over the range of temperature from 70 to 800°C. Curves of thermoelectric power against temperature showed the following regions: (i) less than 1 mv degc⁻¹ at low temperatures, (ii) thermoelectric power increasing rapidly from 180 to 300°C, (iii) constant at more than 2 mv degc⁻¹, (iv) thermoelectric power remaining constant at temperatures up to 800°C for single oxides, but for mixed oxides falling sharply to a slightly lower value at the highest temperatures. After the oxides had been aged at 750-800°C for a year, with no current load, region (i) had disappeared and the thermoelectric power increased rapidly from 70 to 300°C. With barium oxide the
disappearance of region (i) of the thermoelectric power characteristic was accompanied by a similar disappearance of the region of crystal conduction from the electrical conductivity plot (logarithm of conductivity against reciprocal temperature), but there was no change in thermal conductivity. With strontium oxide and mixed oxides there was no such simple correlation between the change in thermoelectric power and the change in electrical conductivity, and the thermal conductivity had decreased. These results are interpreted in terms of Loosjes and Vink's pore conduction theory of an oxide cathode and Metson's work on the thermal stability of the alkaline earth oxides.

Texas Instruments, Inc., Dallas, Texas.


A plasma thermionic converter concept has been proposed which uses cesium permeation through a tantalum emitter to obtain space charge neutralization of electron current from this emitter. The objective of this project was to determine if the permeation rate of cesium through tantalum was sufficiently large for feasibility of the concept. It has been shown that the concept is not feasible because the permeation rate of Cs through tantalum is too small.


This report covers the first six month period of the second year of this contract. In the first annual report, the significance of patchy emission was discussed. In the six month period that elapsed, progress has been made in systematizing this analysis. Experiments have been designed and conducted aimed at investigating and defining "patchiness," and metallurgical techniques have been employed in an attempt to correlate the metallurgical features of emitter surfaces to their thermionic emission. In addition to the above emitter surface studies, work has continued on the current-voltage characteristics of converters.


Attention is called to the dependence of cesium coverage of refractory metal emitters on electric field as well as upon cesium arrival rate (pressure) and upon emitter temperature.

2. Related Phenomena


Studies have been made of the effect of cesium on the field emission characteristics of rhenium and tungsten. These studies were made using a field emission microscope. Cesium was deposited on the emitters after measurements were made on them in their clean state. The work function of each emitter was measured, and cesium was allowed to contaminate the emitting surface. For both rhenium and tungsten there was no radical change in the symmetry of the emission pattern due to cesium adsorption. There was, however, evidence for build up at low work function planes and at plane edges. When voltages in the range of 1500-3800 V were applied, a spontaneous initial migration of cesium was observed starting at the low work function regions of the emitter. The minimum starting voltage for this migration was lower for tungsten than for rhenium and was dependent upon cesium pressure in the tube. The migration was very roughly circular moving toward the edge of the emission pattern. After a time lapse of several seconds, migration proceeded from the pattern periphery back toward the center. The effect was like a contracting ring of brightness which stopped at a certain minimum size then reversed moving again to the periphery of the pattern. The expansion and contraction of this ring repeated itself in cycles with periods of the order of ten seconds. Associated with this migration were fluctuations of emission current at constant voltage ranging from two to ten times the base current on which they were superimposed. The shapes of current versus time wave forms of the cyclic activity were almost identical over periods of several minutes but showed slight continuous changes over longer periods of time. Motion picture studies of these effects have been taken and will be shown. A proposed mechanism for the cyclic migration will be described.
The thermal conductivity of cesium vapor has been measured as a function of pressure at spacings which correspond to a range from a fraction of a cesium mean free path to several mean free paths. The gas conductivity was measured as the increase in power necessary to maintain a hot ribbon filament at a fixed temperature with increasing cesium pressure. A differential measurement with two filaments of different lengths was used to cancel end errors, so that a high degree of accuracy was achieved. The thermal conductivity is independent of spacing at low cesium pressures and is a constant, independent of pressure at high pressure, as expected from kinetic theory. A value of $1.7 \times 10^{-5}$ W/cm·°K was obtained for this high pressure limit.

A preliminary research study was conducted on a new electrohydrodynamic system which is capable of converting thermal into electrical power. Conversion was accomplished by the forced convection of thermionic electrons emitted from an alkaline metal emitter. Analytical and experimental studies showed that this new type of converter is feasible and practical. Outputs up to 18 volts were obtained under open circuit condition with emitter temperatures as low as 450°C. Short circuit output currents were near the emission current of the emitter.

The heat conduction of a cesium gas in a thermionic diode was found by measuring under open circuit conditions the difference in heat flux rejected from the diode collector in the presence and absence of cesium vapor. Different emitter materials and emitter temperatures were employed, as well as different spacings.

The heat conducted between the emitter and the collector of a thermionic diode by cesium vapor is an important fraction of the total heat transport. Equations were developed for the thermal conductivity of cesium vapor based upon the kinetic theory of gases for high, very low and intermediate pressures. In order to apply these equations one must know from experiment the molecular diameter and the accommodation coefficient. The possible ranges for these quantities are given. Since at the conditions existing in a thermionic diode cesium is a monatomic gas, the possibility of additional heat transport in the very low pressure (Knudsen) region by association to Cs$_2$ at the cold surface, or by emission of excited atoms or ions from the hot surface, was investigated. Most cases the thermal effect of association and of excited atom or ion emission was found to be very small. A simple procedure is described for measuring the thermal conductivity of cesium vapor in a functioning thermionic diode. Data obtained by the author are compared with kinetic theory and with results from other laboratories. Agreement between experiments and theory is within an order of magnitude and shows that the phenomenon of heat transport through cesium gas requires additional investigation.

The a.c. retarding potential difference technique has been applied to the study of the reflection of low energy electrons at surfaces partially coated with cesium. The technique is described and results for polycrystalline copper coated with cesium are given. For primary electron energy of 0.5 eV about 20 per cent of the incident electrons are reflected while at 1.0 eV about 30 per cent are reflected.

A summary is presented in this second report of the theoretical study concerning materials for use in thermionic converters. Of those properties required for satisfactory long-lived performance of a material as either the emitter or collector, it was considered that the work function was most critical. Factors relating to the...
crystalline structure, surface, and adsorption phenomena, and the electronic nature of interatomic interactions, are discussed for the following classes of materials: A. Metals, B. Ionic Solids, C. Semiconductors.

4987
Armour Research Foundation, Chicago, Ill.

Metals and alloys germane to thermionic energy converter usage have been screened for embrittlement by liquid cesium metal. The results of the screening evaluations are reported and techniques are described for more detailed studies of ceramics and susceptible metals.

4988
Atomics International, Canoga Park, Calif.

Chemical vapor deposition techniques are being studied as a possible means of producing nonplanar thermionic cathodes having a high degree of uniformity of work function. Vapor deposited molybdenum coatings have been produced by chemical reduction of molybdenum hexafluoride pyrolysis of molybdenum hexacarbonyl and pyrolysis of molybdenum pentachloride. Plating conditions were varied for each process to determine the effect of plating conditions on the preferred orientations of crystallographic planes parallel to the plating surfaces. Both (100) and (111) preferred orientations have been found for the hexafluoride reductions. The pentachloride samples have strong (100) orientations. The hexacarbonyl samples apparently are not pure molybdenum and do not have the expected molybdenum diffraction pattern. (TAB U63-2-4:23, May 15,1963).

4989
Bainton, K.F.

Using planar diode geometry and long pulse measuring techniques, a study has been made of the thermionic emission from samples of UC, UC-ZrC and Ta. Richardson constants deduced for UC (A 55.5 ±3.11) and Ta (A 47.1 ±4.12) are in fair agreement with values obtained by other investigators. The emission from a UC-ZrC solid solution (A 0.44 ± 2.69) was less than that previously reported.

4990
Bondarenko, B.V. and Yermakov, S.V.

The authors investigated the thermionic emission of carbides of metals of groups IV and V over a wide range of temperatures.

4991
Branstetter, J.R.

Many of the high temperature metals and carbides being considered as electrodes in thermionic converters possess spectral emissivities that are sensitive to both wavelength and temperature. For these materials the gray-body procedure for computing the net radiant heat exchange can yield results considerably different from those obtained by the more exact method of summing the monochromatic heat flux over several hundred increments of wavelength. For tungsten, the flux obtained by summation has been shown to be as much as 25 per cent greater than the gray-body flux when both computational procedures were based on the same emissivity data. The present paper discusses current progress towards obtaining spectral emissivity data on other materials (such as tantalum); the amount of emissivity data required for any given material in order to calculate summed net heat flows having good accuracy; the extent to which simple equations can be made to fit these heat flow data.

4992
Denver University, Denver Research Institute, Denver, Colo.

Equipment has been designed and fabricated for the determination of evaporation rates of intermetallic compounds by means of the Langmuir free evaporation technique. Evaporation rate data have been obtained in the temperature range from 900 to 1200°C for metallic beryllium and for ZrBe13, NbBe12 and Nb2Be17.

4993
DeSteese, J.G.

The purpose of this Letter is to report
the appearance of a discontinuity in field-enhanced emission.

4994

The image of the electron emission of uranium carbide is obtained in an experimental microscope in which the object to be studied is heated to emission temperature by electron bombardment. The tests were performed on disks obtained by sintering or by fusion. The difference of emission between the various elementary crystals depends upon the crystalline orientation of the face considered. It is possible to measure the difference between the work functions and to relate this to the orientation of the surface plane. The method enables one to see the influence of surface impurities (e.g.: O2, UO2) and to observe the evolution of grains boundaries during heating.

4995


With the aid of a high-vacuum emission microscope, an investigation was made of the distribution of emission and work functions over the emission surface of an L cathode of pressed tungsten impregnated with aluminates.

4996
Dyubua, B.Ch. and Popov, B.N. METALS WITH HIGH OXYGEN STABILITY OF THERMIonic EMISSION AGAINST THE ACTION OF OXYGEN. Radiotekh. i Elektron., 7:1556-1565, Sept. 1962.


An experimental investigation was made of the stability of thermionic emission of pure metals and those coated with an absorbed film of barium relative to the action of oxygen. The investigated metals, rhodium, iridium, platinum, rhenium, titanium, zirconium and hafnium in comparison with tungsten possess enhanced stability against the action of oxygen. A theoretical treatment of the problem of the increase in stability of emission of thermal cathodes against the action of oxygen was undertaken.

4997
Dyubua, B.Ch. and others. THERMIonic EMISSION OF W-Ti AND W-Hf ALLOYS AND ITS DEPENDENCE ON OXYGEN PRESSURE.

4998

The properties of uranium carbide as a thermionic emitter have been studied in vacuum diodes. The cathodes were tantalum strips coated with a layer of uranium carbide about 1/10 mm thick. The carbide contained excess carbon and was applied to the strip over a thin sintered layer of tungsten powder, which was used to improve adhesion. Water cooled copper anodes were employed. Richardson plot analysis showed that the initial properties were characterized by a work function $\phi$ of 3.9 eV, and an $A$ value of 20,000. Activation occurred during operation at 2000°K for about 50 hr, leading to a peak performance represented by $\phi = 3.3$ eV, $A = 200$. After operation at 2000°K for 180 hr drawing 1 A/cm², the emission fell to half this value, leading to a state with $\phi = 4.6$ eV, $A > 10^5$. It is probable therefore that there is little if any uranium carbide remaining on the cathode at this stage.

4999

The major objective of this research program is to study the effects of long time at temperature on the surface crystal structure of poly-crystalline molybdenum substrates and how these changes in surface crystal structure relate to the performance of cesiated molybdenum emitters for use in cesium vapor thermionic converters for nuclear applications. The investigations are primarily limited to molybdenum and/or vapor deposited coatings on molybdenum as a starting point.
5000

THE THERMIONIC EMISSION OF METALS IN AN
ATMOSPHERE OF VARIOUS GASES. Zhurn. Tekh.


The effect of various gases (O2, H2, CCl4,
NH3, air) on thermionic emission of nickel and
platinum was studied. Experiments on
the action of CCl4 vapors on the surface
of incandescent nickel situated in a stream
of air at atmospheric pressure led to the
conclusion that changes in the total thermo-
ic emission current, after evacuating
the gases which act on the emitter, are
due to changes in the emission of alkali
metal ions. Incandescent platinum was
exposed to the above gases at a pressure
of -10^-4 mm Hg; simultaneous observations
were made on the behavior of the total
thermionic emission current and individual
components of this current, separated by
a mass spectrometer. It was again found
that all changes in the total thermionic
emission current were due to corresponding
changes in the emission of alkali metal
ions.

5001
Ford Instrument Co., Long Island City, N.Y.
THERMIONIC ENERGY CONVERTERS. Emitter
Materials Study, by M. Silverberg, and
L. L. Haring. 73 p., illus., Dec. 31, 1962.
(Final Tech. Rept.) (Contract NONR-3193(00)).

An experimental program was conducted on
selected emitter materials to determine
their potential for use in low temperature
thermionic energy converters. One oxide
emitter and four different dispenser types
were evaluated in parallel plate and
cylindrical geometry in both glass and metal
ceramic construction. With respect to
power density the various dispenser emitter
types showed suitable and reasonably
similar performance. Performance degra-
dation was reversed in some of these diodes
and its mechanism explored and explained.

5002
Garvin, H. L. RESEARCH ON CESIUM-VAPOR CELLS
EMPLOYING CARBIDE CATHODES. Adv. Energy

This paper reports the status of a research
program in which the performance of cesium
vapor thermionic cells employing carbide
emitters is being studied. Vacuum emission
measurements were made on a series of
samples which were polycarbides of uranium
and zirconium. Certain of these carbides
were incorporated into parallel plate
cesium cells in which studies were made of
the electrical output characteristics.
Results indicated that the cells operate in
a discharge mode for cesium pressures
exceeding 0.1 mm Hg and that maximum
power output decreases linearly as the
interelectrode spacing increases.

5003
General Atomic, San Diego, Calif.
CARBIDE CATHODE STUDIES PHYSICAL AND
CHEMICAL REDEPOSITION, by L. Yang, and
(CARTRIDGE 3-2301).

The purpose of the work was to investigate
the possibility of utilizing physical
and chemical methods for reducing the
vaporization loss of UC-ZrC cathodes in a
thermionic cell. The physical method
consisted of the proper selection of
anode temperature, anode material, and
interelectrode spacing so that the
condensation of the vapor of the cathode
materials on the anode would be reduced
or suppressed. The chemical method
involved the use of chemical additives
to transport the vaporized materials back
to the cathode.

5004
General Atomic, San Diego, Calif.
RESEARCH ON CESIUM-VAPOR CELLS EMPLOYING
CARBIDE EMITTERS, February 1 - October 31,
1962, by G. Cheney and F. Carpenter. 37 p.,
Summary Rept.) (Contract NONR-3193(00)).

This report describes the status of a
research program, to study the performance
of cesium-vapor thermionic cells
employing carbide emitters. It has been
established that emission poisoning can
result when a UC-ZrC emitter is exposed
to air after being heated to a high
temperature. Also, the thermionic emission
of UC-ZrC emitters was found to be
independent of composition; however
emitters with a low percentage of UC are
more easily poisoned. Data taken during
the operation of the Mark I-D cell show
that cesium vapor causes a substantial
modification of the thermionic work
function of a carbide.

5005
General Electric Co., Research Laboratory,
Schenectady, N.Y.
THERMIONIC EMISSION FROM METAL CRYSTALS IN
ALKALI METAL VAPORS, by H. F. Webster, and
P. L. Read. 54 p., illus., May 1963.
(SR 2) (AFGL-63-451) (Contract
AF 19(604)-8424).

Thermionic emission microscopes have
been used to evaluate the emission
density from tungsten, molybdenum,
tantalum, niobium, nickel, rhodium, and
niobium carbides in cesium, rubidium,
and potassium vapors as a function of alkali
vapor pressure, emitter temperature, and
emitter crystal face. It was found that when the emitter surface had less than a monolayer coverage of alkali metal, it was the atomically closest packed plane of the emitter which yielded the highest thermionic emission density. The effects of surface contaminants were studied and evidence was obtained suggesting that the high work function of the 112 plane of tungsten and molybdenum may be caused by a contaminant.

5006
General Electric Co., Vallecitos Atomic Laboratory, Pleasanton, Calif.

To meet the needs of nuclear thermionic applications, fuel-emitter materials must possess a combination of specific chemical, nuclear, physical, and mechanical properties. Uranium and thorium-bearing carbides and two selected rare earth hexaborides, EuB₆ and YB₆, have been studied to establish some degree of quantitative knowledge of these materials and the properties most likely to be employed in thermionic applications.

5007
General Telephone and Electronics Laboratories, Inc., Bayside, N.Y.

One phase of this contract has been thermionic emission microscopy of cathodes. In order to gain new insights into thermionic emission mechanisms and phenomena, and to verify existing hypotheses on various factors influencing thermionic emission, including materials, processes, thermal treatment, etc., a systematic study of cathodes has been made by means of an emission microscope that incorporates many of the advances in electron optics and cathode-ray tube technology of the past twenty years.

5008

The operating characteristics of the noble gas plasma diode thermionic converter require that the emitter contain a high surface concentration of enriched uranium. The emitter materials have been limited to uranium carbide of both the ceramic and cermet systems. The ceramic materials investigated were pure UC and the mixed carbide UC-ZrC. The cermet materials investigated were UC-Nb, UC-Mo, UC-W and UC-Re. The chemical reactivity between the uranium carbide and the metal in the four-cermet systems varied quite markedly; the UC-Re system appearing to be the most stable one at 2000K. A reference emitter material composed of 80 v/o UC-20 v/o Re was selected. The emitter discs were fabricated by the gas pressure bonding process. This process can be utilized to densify the core and simultaneously clad and bond the core into an integral assembly in a one-step operation. Results of the fabrication studies as well as some thermodynamic considerations for the cermet systems are presented.

5009
Hopkins, B.J., Ross, K.J. and Blott, B.H.

Work function measurements are reported for carburized tantalum cathodes coated electrophoretically with uranium and zirconium carbides. Thermionic methods for the determination of work function have been used together with the Zisman modification of the Kelvin technique. The poor agreement found between the two sets of results is thought to indicate that thermionic emission takes place from only a fraction of the total cathode area. Work function measurements have also been made on the thin films that evaporate from these cathodes during their operation at high temperatures on to fixed anodes. When the cathode is uranium carbide, our measurements can be interpreted in terms of an evaporated film of uranium metal and uranium monoxide on the anode surface. All of this work has been performed under ultra-high vacuum conditions.

5010
Ingold, J.L., Blue, E. and Ozeroff, W.J.

The thermionic properties of polycrystalline bulk samples of several refractory metal carbides in vacuo and in cesium vapor have been determined. Some typical Richardson plots of experimental data obtained by a low-field method are shown, and a summary of the results is presented in tabular form. Most of the carbides investigated can be characterized by an emission constant in the
range 40-90 A/cm²-deg² and a work function in the range 4.0-4.2 V. In addition, current-voltage characteristics typical of those obtained for the same carbides immersed in cesium vapor are shown. No gross differences in the cesium characteristics of the different carbides were observed. Finally, current-voltage characteristics obtained for a thermionic converter operating with a collector temperature in excess of 1000ºK are shown. A power output of 4.5 W/cm² was obtained for a planar Cs-on-Ta converter at an emitter temperature of 2250ºK and a collector temperature of 1725ºK.


Lanthanide hexaborides have been shown to cover a wide range of thermionic work functions. This range covers the span of 2.2 to 4.9 eV. It is the object of this paper to discuss the materials problems encountered in working with these emitter materials. The materials studied were YB₆ and EuB₆, the first having the lowest reported work function of the hexaborides (2.2 eV), the second having the highest work function (4.9 eV). The following topics are discussed. 1. Synthesis of the hexaborides. 2. Fabrication of the hexaborides. 3. Bonding of the hexaborides to refractory metal substrates. 4. Sublimation behavior at high temperatures and decomposition products. 5. Compatibility of the hexaborides with cesium. 6. Summary of physicochemical properties of YB₆ and EuB₆.


The measurement of the effective work function of a cesium-covered emitter as a function of emitter temperature and cesium pressure provides an important insight into the adsorption phenomena. In this paper, experimental data on the work function of molybdenum, tantalum, rhenium, iridium and other refractory metals, over a range of emitter temperature (1500-2000ºK) and cesium pressures (0.01-3 mm Hg), is presented. A model of the adsorption process, in good agreement with the trends shown by the data, is also given. A useful manner of presenting the experimental data is provided by the fact that curves of constant work function are straight lines when plotted on a plane of logarithm of the pressure vs. reciprocal temperature.


It has been observed that under certain circumstances a relatively large amount of material has been transported from a molybdenum thermionic emitter to the collector. Because of the serious implications of this transfer on diode life, an analysis of the chemical system within a cesium diode has been made. The various chemical species expected, and their interactions under various conditions, are described. It is shown that a gross transfer of molybdenum is not likely in a system having only oxygen as an impurity. However, if hydrogen is also present within the diode, a mechanism for gross transfer of molybdenum is established, and a serious transfer problem will be produced. The analysis is extended to consideration of other emitter metals.

Radio Corp. of America, Electron Tube Division, Lancaster, Pa.


Initial measurements use deposition of molybdenum from a molybdenum cathode onto a nickel anode in the presence of cesium vapor showed a significant reduction over that for vacuum evaporation. The ribbon filament in these experiments was heated electrically and the quantity of deposited molybdenum determined by spectro-chemical analysis. Four cathode-anode spacings were provided to determine the dependence of the deposit on spacing. These initial results have been refined and extended to cover a larger range of emitter temperatures and cesium pressures.

The conventional plasma thermocouple or thermionic energy conversion diode has a solid metal electron collector. Cesium vapor at a pressure of a few millibars or less is widely used to provide ions for electron space charge neutralization. Usually conditions are such that a monolayer of cesium coats the collector, so that electrically the collector appears to be cesium. This suggests the use of a diode with a liquid metal collector material such as cesium, rubidium, or potassium and their alloys. Recent experiments at this Laboratory have shown that a diode can be produced consisting of a hot emitter and a liquid metal collector separated by the vapor film created in film boiling. In such a diode the metal vapor pressure can be brought in the range of a few millibars or less by, for example, controlling the pressure of an inert gas blanket which covers the film boiling liquid. If conditions in the film are appropriate for production of plasma a thermionic energy conversion plasma diode results.

Two types of diode using a film boiling liquid metal electron collector have been suggested for the direct conversion of fission heat to electrical energy: (1) uranium-bearing carbides which also function as the nuclear fuels, and (2) refractory metals fueled with uranium containing oxides or carbides. Irrespective of what happens in a reactor, there are certain conditions which have to be met before these emitter systems can be of any practical value. For the carbide emitters, the rate of material loss by vaporization should satisfy the designed life expectancy at temperatures where useful performance is obtainable. For the refractory-metal emitters, the diffusion of the components of the fuels into the metals should not impair their electron-emission characteristics. The purpose of this paper is to analyze these aspects on the basis of existing experimental data and to discuss the current status and problem areas with regard to the feasibility of these two emitter systems.

D. Plasma Properties


Electrostatic probe measurements have been made in a cesium plasma with an electron number density of \(10^9/cm^3\) which is generated in a thermionic converter operating in the non-arc mode condition. Experimental results obtained using a conventional electrostatic probe with borosilicate glass as the electrical insulating material around the probe shank indicate that there is both surface and bulk electrical conduction through this material when it is placed in a high temperature cesium plasma. This surface leakage significantly changes the current-voltage characteristics of the probe so that the correct plasma properties cannot be obtained from this information. Tests of several other electrical insulating materials indicated that similar problems with electrical conduction were present when the probe was inserted in the cesium plasma. A novel probe design is described which is comprised of a coaxial metal cylinder sandwiched between two layers of insulating material around the probe shank.

potential in the plasma region of low temperature thermionic converters were determined by means of a pulsed Langmuir probe technique. The spatial distributions of these parameters, in parallel plate geometry, were measured with the aid of movable probes within the operating converters. The experimental values are shown to be consistent with reasonable physical models. Spectroscopic measurements were made in both the visible and infrared regions and the validity and applicability of the results are discussed. Results obtained from converters, in which small amounts of oxygen were present in the discharge region, are explored. The effects of cesium and "patch effects" on the surface characteristics of impregnated tungsten emitters are discussed on the basis of a theoretical analysis and experimental results with numerous test cells.

5022

Measurements were made of the voltage-current characteristics of an independently produced plasma between two emitting electrodes. It is shown that the observed characteristics can be accounted for by the changes of the sheath voltages at the two electrodes, the plasma remaining closely unipotential. (Phys.Abs.,66:4155, Mar.1963).

5023

It was suspected for some time that the ion current $J_i$ required for establishing a cathode sheath and drawing out an electron current $J_e$ is less than the value $(m/M)^{1/2}J_e$ required by Langmuir's theory. This has now been proved experimentally. In the experimental device the main discharge space between emitter and collector was supplied with ions through the meshes of a metal gauze, from an auxiliary glow discharge. Probe measurements indicate electron temperatures of the order of 0.15-0.25 V in an argon discharge, confirming that all ions are introduced through the gauze. By multiple collisions almost perfect temperature equilibrium is established between ions and neutrals. The small ion drift current could be calculated from the measured electric and density gradients, with known values for ion mobility, and was found, in an example, about 100 times smaller than required by Langmuir's theory. The average energy of the ions at the emitter was calculated as about 0.5 V. This leads to the conclusion that ions of such low energy are not absorbed by the emitter, as was hitherto assumed, but are reflected with a high probability. The ion space charge in the cathode sheath is in fact very nearly as required by Langmuir's theory, but it is produced by ions which are reflected about 50 times at the emitter before they are absorbed.

5024

A theoretical analysis of the space charge problem for a cesium plasma diode shows that operating conditions can be achieved for which there exists no simultaneous solution of the space charge and converter equations which relate current, voltage, and load impedance. These conditions correspond to those for which internal relaxation oscillations have been experimentally observed in a cesium vapor type thermionic energy converter. Examination of the normalized distance parameter used in the analysis indicates that potential distributions having a large number of potential maxima and minima may exist in the cesium plasma diode. This explains some irregularities found in the load characteristic and in plasma temperature measurements for the plasma diode.

5025
Hughes Research Laboratories, Malibu, Calif. CESIUM PLASMA STUDIES FOR THERMIONIC ENERGY CONVERSION, PHASE II, by J.Y. Wada and R.C. Knechtli. 21p., illus., Dec.1962. (Semi-Annual Tech.Summary Rept.) (Contract Nonr-3501(00)).

The thermalization of an electron stream injected at a controlled energy (up to 7 eV) into a quiescent cesium plasma has been observed. The plasma heating associated with the thermalization of the injected electrons has been measured and was found to be in general agreement with theoretical expectations. The resistivity of a highly ionized quiescent cesium plasma has been measured for small current densities (negligible ohmic heating of the plasma), at temperatures between 2000 and 2500°K. The measured values of resistivity were found to be in good agreement with those theoretically predicted by Spitzer.

5026
Hughes Research Laboratories, Malibu, Calif. CESIUM PLASMA STUDIES FOR THERMIONIC ENERGY CONVERSION, PHASE II, by R.C. Knechtli. 2v., 1962, 1963. (Q. Ltr. Repts. 2 & 3) (Contract Nonr-3501(00)).

Measurements of the resistivity of a
ionized cesium plasma for small current densities have been completed. The experimental values of resistivity of initial measurements and subsequent results were found to be in good agreement with those theoretically predicted for a highly ionized plasma in which Coulomb electron-electron and electron-ion collisions are predominant.


A plasma-sheath theory is described for computing the V-I characteristics of noble gas thermionic converters. Application of this theory in the form of an IBM computer code to laboratory and inpile experimental data is presented. The assumptions in the theory are twofold: (1) a spatially uniform ion density is assumed in the interelectrode plasma between the emitter and collector sheaths; and (2) the ion loss rate is taken to be independent of the diode voltage. The basic plasma sheath equations are presented and the operation of the computer code to produce the theoretical voltage-current characteristics is outlined. The experimental data from the operation of laboratory and inpile thermionic converters are analyzed by adjusting plasma parameters to fit the theoretical to the experimental voltage-current characteristics.

Many studies about cesium plasma cells have been reported, but it seemed to the authors that there were few in which one could combine experimental results with theoretical ones in the sense that these experimental studies were carried out only in an operating region of almost constant cathode work function, that is, considerably high cathode temperatures. Our measurements were done only in the region of low cathode temperature and low gas pressure in which the interelectrode spacing was less than the mean free path of electrons, in order to examine these theories. The efficiency agreed well with one of these theories. Open-circuit voltage was also observed.


The potential distribution in a diode filled with low-density plasma under the assumption that the potential between electrodes is nonmonotonic is considered. Under these conditions it is necessary to take account of particles that are trapped in the potential wells produced near the extrema of the potential. A complete solution is given of the problem for several cases in which the distribution of trapped particles is a Boltzmann distribution. The corresponding portions of the voltage-current characteristics and the voltage drop across the diode are obtained.


Recent research has demonstrated that the flow of an electron beam through a plasma is unstable. Specifically thermal fluctuations of the beam and plasma particles are amplified by an interaction between the electron beam and the plasma electrons. This interaction can result in the extraction of power from the electron beam. This report is concerned with the study of the beam-plasma interaction and the consideration of it as a possible mechanism for the heating of plasma electrons.


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accelerated in the plasma space by this injection potential. The analysis given shows that at the open circuit condition, the energy distribution of the electrons at the plasma edge of the emitter sheath cannot be a true Maxwellian over the entire range in electron energy. Instead, it is thought to be made up of two quasi-Maxwellians. The low energy electrons are trapped and may have a high average energy close to that of the injection potential. The untrapped electrons will have an electron temperature equal to that of the emitter and their density will be that associated with an apparent or fictitious density many times that of the actual density. The theory is developed to describe quantitatively the relations that must be satisfied for the above description to apply.


Indications from voltage-current curves of thermionic power converters suggest enhanced ionization at, or very near, cesium-coated surfaces. Experiments are now being conducted to study this phenomenon quantitatively. The tube contains three indirectly-heated tantalum surfaces surrounded by a shield. These heated surfaces are tantalum tubes located at the three corners of an equilateral triangle. The extension of a line from the corner El perpendicular to the base of the triangle formed by the line E2 and E3 serves to locate the position of a fine-wire ion collector. Electrons are accelerated from surfaces E2 and E3 to bombard El. Ions produced at or near El are then accelerated toward the ion collector to serve as a measure of the ion production. Results of this experiment will be discussed in detail.


Very little information is available regarding the properties of a cesium plasma. In this report, thermodynamic and transport properties of partially ionized cesium vapor, or plasma, are determined from theory (supplemented by available experimental results). Such information is essential in predicting efficiencies of the cesium plasma diode converter. Emphasis is placed upon the transport properties of electrons and the effects of neutral atoms on the thermodynamic and transport properties. Cesium vapor, in the region of small fractional ionization, is considered as a non-ideal gas obeying the virial equation of state.
surface ionization mode of operation, is characterized by an output current density which represents a fraction of the Richardson saturation current density and the second mode, the volume ionization mode of operation, is characterized by an output current density which is approximately an order of magnitude higher than the surface ionization current density.

5038

The space charge problem for a plane diode whose hot cathode emits both ions and electron has been considered by Hernqvist and Johnson, and by Auer. This model is appropriate for the analysis of the low pressure cesium-filled thermionic converter in which the ions are generated by surface ionization at the cathode. Further, the electrode spacing must be such that the assumption of no collisions is valid. These authors describe the variety of potential distributions that can arise, but give few numerical results. The present paper systematizes and discusses the numerical results of machine calculations for potential distributions with various ratios of emitted electron to emitted ion density, electrode spacings, and applied potentials. Some analytical results, e.g., the necessary and sufficient conditions for the establishment of certain types of potential distributions, are given. Some typical theoretical V-A curves are compared with experimental data.

5039

Theoretical calculations and experimental data are given for a hot- and cold-electrode converter for extracting electrical energy from a high-temperature plasma. Unlike other plasma converters, this can be a high-voltage generator. An efficiency of 36% has been obtained at a power level of 25W, and an efficiency of 67% may be possible at thermonuclear temperatures.

E. Design Parameters

5040

In French. The general equation for efficiency is derived in optimized conditions, in terms of the two fundamental parameters: anode work function and cathode quality factor. An optimum efficiency is calculated from the resulting expression. The relative magnitude of conduction and radiation losses is pointed out. Sets of curves are given for various anode work functions. (Battelle Tech.Rev.,11:534a, Dec.1962).

5041
General Atomic, San Diego, Calif.

A digital-computer code which describes the performance of thermionic diodes has been developed. Detailed data derived from physics research on operating thermionic diodes are incorporated in the library of this code. With the data now available, semiquantitative estimates can be made of these diodes in a reactor environment. These estimates are useful in the initial evaluation of the feasibility of thermionic systems.

5042
General Electric Co., Research Laboratory, Schenectady, N.Y.

It is shown that an optimum geometry exists for a cylindrical electron bombardment heater in which maximum thermal flux is to be delivered with stable operation and long life of the bombardment heater coil. The procedure for finding the stable operating condition is illustrated, and the optimum heater size is evaluated.

5043

Attempts to work out practical designs for thermionic direct converters capable of converting heat energy to electrical energy have the problem of finding suitable emitter materials. Sonic thermionic properties of several potential emitters are listed.

F. Devices

5044
Atomics International, Canoga Park, Calif.
FLAME HEATED THERMIONIC CONVERTER RESEARCH, July 1 - December 31, 1962, by W.R. Martini, and E.V. Clark. 2v., illus.,
The purpose of this research is to develop the technology required for portable, flame-heated thermionic power sources. Active development in thermionic diodes, heat sources and materials is underway.

5045
Atomsics International, Canoga Park, Calif.

Uniform work functions of thermionic converters were investigated. The performance of cylindrical converters which have emitters with uniform work function surface was evaluated. Chemical vapor deposition techniques were developed for the fabrication of nonplanar emitters of practical design which have improved uniformity of work function over the uniformity of work function of standard polycrystalline emitters. The development of thermionic converters having emitters of improved uniformity of work function may result in increased efficiency and power density. A converter test stand was assembled, equipment associated with the test stand was calibrated, and deposition samples were fabricated. (TAB U63-1-2:39, Jan. 15, 1963).

5046

"State-of-the-Art" of thermionic energy conversion is briefly covered in this paper. Basic operating principles of thermionic energy conversion are outlined. The problem areas of cesium attack, emitter and collector and converter fabrication techniques are discussed. Application of thermionic converters to solar, nuclear and fossil fuel heat sources is covered. Data on efficiency, power density, weight and life results with various sources are presented.

5047

This paper deals with a method for space charge compensation in noble gases and with the performance of a special thermionic converter with operating temperatures not exceeding 1300°K. Low work function collector materials (6e-1 V) are feasible in high vacuum or in noble gases only. Positive ions of noble gases for electron space charge compensation are produced in an auxiliary discharge. The influence of the low pressure plasma on the efficiency of conversion is investigated experimentally in different noble gases. Values of experimental devices are given: Mean efficiency of conversion 8 per cent, highest efficiency obtained 20 per cent. Output power density of emitter surface 1 W/cm².

5048

In German. Based on a theoretical treatment of the efficiency of thermionic energy converters, experiments were performed using models of a new converter type with cathode temperatures not exceeding 1000°C. The influence of a low-pressure plasma being generated in an auxiliary discharge on the efficiency and the dependence of pressure and kind of gas was investigated. Noble gases with large mass numbers were proved to be advantageous. The output current was controlled by the auxiliary discharge. By this means it was possible to use the converter as an a.c. generator operating at frequencies up to about 1000 c/s. (Phys.Abs., 66:3997, Mar. 1963).

5049

In French. The review of the direct transformation of heat into electricity is divided into two basic sections-electronic emission with surface ionization and surface ionization of cesium on tungsten. A number of specific applications to converters is given. A very recent biography is appended. (Nuclear Sci.Abs., 17:2113, Jan. 31, 1963).

5050

The research work on thermionic converters accomplished at Thermo Electron is reviewed. Data obtained for converters, using niobium, tantalum, tungsten, iridium, and rhenium emitters, as a function of interelectrode spacing and converter operating temperatures is given in the form of maximum power density maps. Where
pertinent, references to the original publications are given. Theoretical work on the effect of crystallographic orientation of emitter surface on converter performance is described. General design requirements for solar thermionic generators for space applications are discussed. Generators can be designed to have the fast warm-up characteristics that must be achieved in satellite applications. Work done at Thermo Electron on cylindrical monodiode and cubical multidiode generators is described. Although no inherent limitation has been observed on the life and reliability of thermionic devices, life of the order of several thousands of hours and higher reliability must be and remain to be demonstrated. (STAR, 1:16, Jan.8, 1963).

5051

The advantages and disadvantages of thermionic diodes using liquid collectors are reviewed. It is pointed out that one of the major parameters upon which the practical value of such devices depends is the depth of immersion that the emitter walls can have without resulting in instability of the film boiling process. The flow conditions in the film are derived from first principles. These are then combined with the Helmholtz stability analysis for the boundary between two fluids to find the maximum depth of immersion that the heat source walls can have in a stable film boiling regime. It is also pointed out that, generally, only a fraction of this maximum immersion depth can be used owing to the excessive film thickness that is otherwise achieved near the liquid surface and for which no useful diode output can be obtained. Expressions for the film thickness and vapor velocity in the film are given. The results of mercury and cesium film boiling experiments are discussed. The major conclusion reached is that intense cooling of the film interface with the liquid is required in order to achieve depths of immersion exceeding one inch in practical cesium devices.

5052
California University, Lawrence Radiation Laboratory, Livermore, Calif.


Design and construction features are presented for a parallel-plane thermionic converter tube which has an interelectrode gap that may be precisely varied from zero to 6 inches. (STAR, 1:17, Jan.8, 1963).
described. Typical results obtained with this system are as follows: Output power 2 W, ratio of output power to injection power 5:1, measured thermal efficiency 2 per cent.

5055

Experiments with Cs plasma triodes have shown three distinct types of oscillations which may be of interest in energy conversion work. One mode of operation is analogous to conventional vacuum triode operation, another is a low frequency mode which exhibits several interesting features, and the third is a way of coupling to the spontaneous plasma oscillations. These modes are presented and are discussed in terms of the ionized medium conditions.

5056

In Czechoslovakia, an interpretation is given of the physical processes in the activity of a thermionic converter. Information is presented on the state of research into practically applicable thermoelectron converters. Types of converters are mentioned: a vacuum converter with a small distance between the electrodes; and a converter with cesium vapors, the construction of which is technically simpler. Three kinds of working regimes are described for the converter with cesium vapors: Knudsen, diffusion, and plasmatic. These regimes are evaluated from the point of view of suitability for application. In connection with the conversion of nuclear into electrical energy in a thermionic converter, a description is given of an existing converter. (Nuclear Sci. Abs., 17:20649, June 30, 1963).

5057

Information is presented on the status and results obtained in the following 4 areas: (1) sample processing investigations, (2) grain growth experiments in vacuum and cesium vapor environments, (3) long term cesiated emission tests from such substrates which are undergoing surface crystal changes and (4) electron emission microscope examinations of initially polycrystalline materials which are operated long times at high temperatures.

5058

The development of a high-temperature, vapour-filled thermionic converter for application with a nuclear reactor for space-vehicle electrical power generation is described. Problems associated with the design and operation of a thermionic converter employing a UC-ZrC emitter, a cesium plasma for space charge neutralization, and a high-temperature collector are described. Emitter fabrication techniques are also described. A test cell employing a cylindrical UC-ZrC emitter, which was pressure bonded to a tantalum sleeve, and a low-temperature copper collector, was fabricated and operated for 400 hours to provide experimental data. The emitter was operated at temperatures of the order of 2000°C while the collector temperature was maintained at 200 to 300°C. A conceptual design study for a thermionic power reactor incorporating the thermionic converter under development is also included. (TAB U62-4-6:32, Dec. 15, 1962).

5059

A description of the theoretical study, design, and test of a thermionic generator; utilizing solar energy concentrated by means of a parabolic collector. The generator produced 21.25 watts at a cathode temperature of 1775°C in solar test with a five foot diameter, sixty degree rim angle, parabolic collector. Expected future performance of solar thermionic systems are discussed.

5060

The effort during this second quarter of the program has been directed toward the completion of the life test equipment, initiation
of life tests, and the acquisition of operational data.

5061
General Electric Co., Schenectady, N.Y.
EVALUATION OF A MOLYBDENUM EMITTER, LOW VOLTAGE ARC THERMIONIC POWER CONVERTER, by E.A. Baum. 100p., illus., Feb.1963. (Final Rept.) (ASD-TDR-63-183) (Contract AF33(657)-8323).

Results of life tests on the planar molybdenum-emitter cesium-vapor thermionic converter operating under steady-state conditions are presented along with a description of the life-test equipment. Transient data on the effect of variations in cathode, anode, and reservoir temperatures, as well as step changes in the load, are also presented.

5062
General Electric Co., Research Laboratory, Schenectady, N.Y.

Measurements made on a Cs-vapor thermionic converter having a 13.3 cm² Th-W emitter indicate that in the retarding range of the converter the emission cooling is just what simple theory would predict. However, for collector-to-emitter voltages more positive than approximately 1.3 volts, the emission cooling fell far below that predicted by simple electron emission from the emitter, indicating that large amounts of power (as much as 20 watts/cm² at positive collector voltages) was flowing from the plasma back to the emitter. This anomaly in the emission cooling is interpreted in terms of resonance radiation, excited atoms, and ions returning to the emitter. These originate in a region of high electron temperature adjacent to the emitter.

5063
General Electric Co., Research Laboratory, Schenectady, N.Y.

A thermionic converter is described in which the emitter is made of a single crystal of tungsten which has been cut to expose 16 square centimeters of 110 surface. Details of the cathode surface preparation, anode construction, and assembly techniques are presented along with some operating characteristics from the first successful run. The output power was not as large as expected. A second run following reprocessing demonstrated improved performance particularly at low cesium pressures.

5064
General Motors Corp., Allison Division, Indianapolis, Ind.

The capillary emitter is a new approach to thermionic energy conversion - in this concept, cesium flows through a refractory emitter structure so that the emitter becomes a dual source of ions and electrons. To determine the fundamental performance characteristics of the capillary emitter, a theoretical and experimental study was conducted on a monocapillary configuration. This report summarizes the results of the investigation. (STAR, 1:653-16307, Jly.8,1963).

5065
Thermo-electron engine developed by MIT professors G.N. Hatsopoulos and Joseph Kaye produces small quantities of electricity with 12% efficiency.

5066
ITT Industrial Laboratories, Fort Wayne, Ind.

Difficulties in realizing a very small anode-cathode spacing, due to uneven thermal expansion and warping, have led to a feasibility study of a subliming anode surface that automatically maintains the proper spacing from the cathode. Barium was chosen as a subliming metal since it serves also to activate the cathode. This required that all parts of the vacuum enclosure be held above 500 degrees C. Effects of barium corrosion at high temperatures were studied. (TAB U63-1-6:26, Mar.15,1963).

5067
Kitrilakis, Sotiris and Hatsopoulos, G.N.
Extensive data obtained on the performance of a cesium vapor diode thermionic converter are described. Volt-ampere characteristics were obtained for four spacings from 0.002-0.019 in., emitter temperatures in about 50° steps from 1600-2050°K, and cesium pressures to 30 torr. A set of such data for emitters of Nb, Ta, Mo, W, Re and Ir have been obtained. Heat flow through the converter could be measured by an attached calorimeter. A systematic method is described for evaluating the practical significance of this large amount of data to permit the choice of optimum materials and operating points for efficient engineering design. Evidence is presented that the observed saturation current of the extinguished mode represents true temperature-limited emission, and thus may be used to obtain data equivalent to the Langmuir S curves.

5068

A theory of auxiliary discharge thermionic energy converters is presented. This theory permits the prediction of a converter's I-V characteristics as functions of auxiliary discharge current, auxiliary discharge voltage and geometry. It also permits the prediction of the resistive voltage drop across the plasma as a function of load current. Measurements of auxiliary discharge converter I-V characteristics were performed with auxiliary discharge current and voltage as parameters. These measurements are presented and compared with theoretical predictions. The relatively low auxiliary discharge currents, low auxiliary discharge powers, and low plasma resistivities observed in these experiments are found to be consistent with the theory.

5069

In Czechoslovakia. Explains the basic properties of this convertor and calculates its efficiency, assuming perfect charge compensation in the space between the electrodes. Results of these calculations are applied both to a device with a tantalum cathode and to one with an impregnated barium cathode supported by porous tungsten. (Elec.Eng.Abs.,60:6233,June 1963).

5070

Three cylindrical thermionic converters with emitters of tantalum, molybdenum and niobium have been built and are being life tested. They were designed specifically for life tests in air with electron bombardment heating. The dimensions and operating temperatures chosen are considered reasonable for a nuclear reactor application. Design details are presented and output characteristics such as functions of cesium pressure and emitter temperature are given for each converter. All three devices are now operating and have run from 2200-3300 hr. Although they have not yet achieved the normal life of a nuclear fuel element, it is encouraging that no basic failures have been experienced.

5071

A solar test program carried out on a prototype thermionic generator is described. The program, which is designed to evaluate the performance of the generator in conjunction with a five-foot precision solar concentrator, shows the ability of such a combination to produce very nearly its design power output levels in a space environment. A description is given of all specialized equipment and techniques employed in carrying out the tests and evaluations. The pertinent data and results are summarized and analyzed for all major phases of the solar test effort. These major phases include the evaluation of concentrator efficiency, flux profile and power distribution measurements, cavity absorber efficiency, the environmental chamber and the influence of the transparent vacuum enclosure, a comparison and correlation of solar test generator performance with laboratory test data, and an extrapolation of the earth-bound test results to the true space environment. (Nuclear Sci.Abs.,17:9134, Mar.31,1963).

5072

Continuing studies are described on the operation of thermionic energy converters in the low-voltage arc mode at emitter temperatures of 1070°C to 1400°C. Additional data have been obtained on the degradation in performance of a thermionic
converter with molybdenum emitter after the converter is processed. Large changes in output power are observed before stable performance characteristics are achieved. No significant difference has been obtained between the performance of molybdenum emitter converters with stainless steel or molybdenum collectors. The ignition potential of a molybdenum electrode converter operating at low emitter temperatures was found to change in the direction of positive power output as the emitter temperature was increased or as the collector temperature was decreased. Operating conditions for optimum power output from a converter do not correspond to the conditions for the optimum positive ignition potential. Qualitative data are presented on the discharges observed in a converter for different cesium vapor pressures.

5073
Martin Marietta Co., Nuclear Division, Baltimore, Md.
A STUDY PROGRAM ON CESIUM VAPOR-FILLED THERMIonic CONVERTERS HAVING IRIDIUM EMITTERS, November 1, 1961 - October 31, 1962, by M.F. Talata, D.S. Trimmer, and A.J. Kennedy. 87p., figs., Dec.1962. (Yearly Summary Rept.) (Contract Nonr-3639(00)).

An extensive mapping of the performance of cesium vapor-filled energy conversion devices was obtained for the high vacuum work function emitter materials, iridium and rhenium, for the interelectrode gap of .030". Characteristic current-versus-voltage curves and summaries of the output power density and efficiency are given for the emitter temperature range of 1550-2000K and the cesium temperature range of 475-600K. The data shows a systematic superiority of iridium to rhenium.

5074
Martin Marietta Corp., Aerospace Division, Baltimore, Md.

The engineering design of the double diode thermionic power generator was completed. Fabrication of several component parts was initiated. The parts for the fueled emitters are almost completely fabricated with only assembly and final machining remaining. The manufacture of other generator components including the collector temperature control assembly and the ceramic-to-metal seals was initiated. The engineering design of the clad fuel elements was completed and the first element, similar in configuration to the fueled emitter, was fabricated. This element will be used to determine the changes in the vacuum emission characteristics over a 200 hour test period. The vacuum test chamber was fabricated and is undergoing preliminary outgassing. (Nuclear Sci.Abs.,17:11513, Apr.15,1963).


The behavior of a thermionic energy converter filled with cesium vapor was studied.

5076
National Aeronautics and Space Administration, Washington, D.C.

An approach to decreasing the interelectrode space charge of a magnetic triode was tested by using a shaped magnetic field to improve triode performance. The shaped field was designed to restrict the electrons to circular orbits and thus to decrease electron-electron collisions and/or electron scattering. A percentagewise improvement in the triode output power was observed with the shaped magnetic field. This improvement in the performance, however, was not of sufficient magnitude to make this particular triode a practical energy converter because the grid power loss was of greater magnitude than the power output.

5077
Ogle, H.M., Samstad, G.I. and von Damm, C.A.

Several in-reactor tests of plasma diodes have been performed at the Valeclitos Atomic Laboratory to gain design information for reactor thermionic fuel elements. These experiments were designed to furnish data in three major areas: (1) Comparison of out-of-pile performance and in-pile operation; (2) Special diode fabrication techniques which are required for in-pile operation; and (3) Test facility requirements for adequate control of converter parameters.
Thermionic Cavity Generator Development
Purdy, D.L.
ARS Preprint no. 2572-62.
Prepublication Copy.

Work performed on a cavity vapor generator is discussed, and attention is given to the expected performance of future solar-thermionic space-power systems. The system considerations involved in collector and generator relationships, as well as converter-to-generator sizing, are discussed. Computations are described that define the thermal and electrical performance of the converters, cavity insulation, collector, and vacuum system. Measurements of thermal energy and electrical power obtained during laboratory testing are described, resulting in a converter efficiency at a cathode temperature of 1650°C of 6.5%. A description of a solar test and expected solar test results is included. (Nuclear Sci. Abs., 17:9130, Mar. 31, 1963).

Radio Corp. of America, Industrial Tube Products, Lancaster, Pa.

Progress is reported on research conducted to improve the efficiency and life expectancy of thermionic energy converters for space applications. (TAB U63-1-2:35, Jan. 15, 1963 & TAB U63-2-3:16, May 1, 1963).

Radio Corp. of America, Princeton, N.J.

An analysis of the cesium vapor arc discharge is described. A duo-emitter diode for microwave studies of a cesium plasma and its application in a circuit are described. A test station for the monitoring and control of the gas environment in an operating cesium diode is described.

Radio Corp. of America, Princeton, N.J.

Studies of the plasma density variation with discharge current are described both for a synthesized cesium plasma and for a cesium arc discharge. Preliminary experiments with a gas-analysis, gas-dosing system are described. The experimental verification for ball-of-fire analysis of the cesium arc discharge is summarized.

Republic Aviation Corp., Farmingdale, N.Y.
MagnetiC Field Effects in Thermionic Plasma Diodes, by A. Schock and others. 43 p., illus., Jan. 1963. (Final Tech.Rept.)(RAC-1102) (Contract Nonr-3285(00)).

Experiments to determine the effect of transverse and longitudinal magnetic fields on thermionic current transmission are described. The results obtained are in qualitative agreement with theoretical predictions, and suggest the possibility of using magnetic modulation for a.c. generation.

Steele, H.L. and Gillette, R.B.

Several investigators have reported that a thermionic converter with a given emitter temperature can operate in either a high current or a low current mode. In earlier published work, the high current mode was attributed correctly to volume ionization. At that time, the conclusion that volume ionization was occurring was based on the appearance of a glow in the space between emitter and collector as the voltage of the collector was made more positive. The discontinuity in the volt-amper curve at this breakdown voltage is very definite. The phenomenon was studied irrespective of whether it occurred in the power quadrant or with a positive potential applied to the collector. A detailed analysis of this phenomenon now can be presented. At low emitter and low cesium control temperatures breakdown occurs when a potential drop near the collector is equal to the ionization potential of cesium. At the high emitter and high cesium control temperatures, the breakdown occurs at higher currents with potential drop as low as 2 V. This indicates that ionization of excited cesium atoms is occurring when the converter is operating in the power quadrant. The V-A curve in the arc mode is logarithmic, and the voltage at which maximum power occurs is equal to the voltage equivalent of the electron temperature.

RF Oscillations and Power Output in Alkaline Thermionic Converters, by H.K.
Experiments were made using a potassium plasma cell with a Ta emitter and a Ag-plated Cu collector. The r-f frequencies, rms voltages, power output, and other quantities were measured under various conditions of emitter temperature, potassium vapor pressure, and d-c and r-f loads. Ion and electron densities were calculated and compared with the oscillations occurring. (Nuclear Sci.Abs.,17:11837, Apr.15,1963).

A brief survey of basic research on thermionic converters refers to the work function of various materials and to the physics of low-voltage Cs plasmas. A brief description of device research contains information on converter tubes using Ta, Mo, and Nb as emitters, respectively. The tubes were operated in air for fairly long periods (>2500 hrs. continuously, in one case). Power yield varied from 2.5 to 4.55 w./sq.cm. for the different tubes operated at emitter temperatures 1950-2080°K., and at collector temperatures 875-1000°K. Tube construction is illustrated with a cross-sectional drawing. (Chem. Abs.,58:2928, Feb.18,1963).

Parametric studies are being conducted utilizing both cylindrical fixed spacing and parallel plane, variable-spacing thermionic converters. A brief description of the design and fabrication of these converters is given, and the techniques of component preparation, the use of getters and the philosophy of operation are illustrated.

Evidence is presented that suggests that an auxiliary discharge to a guard ring increases the output power of these converters. While driving one tube with a 60 c/s transformer, a current of 110 A/cm² was drawn at an emitter temperature of 2000°K and with the collector 1.5V positive.


No longer merely "interesting" as back-up devices, converters today warrant serious consideration for space vehicles. A solar-heated system could be ready for test flights within the next two years.

G. Systems
loop configuration; Main heater; Heat sink; Surge tank; Thermionic generators. (TAB U63-2-4:17, May 15, 1963).

5092
Atoms International, Canoga Park, Calif.

Electrical power degradation from the operation of many series-parallel circuited cesium diodes in a thermionic reactor must be considered when a nonflattened nuclear power distribution exists over the volume of the reactor core. This experiment measures the loss of power and efficiency due to unequal heat inputs to series- or parallel-connected diodes, and studies the operating characteristics of a multiple-diode system. The results are applied to a specific thermionic reactor configuration with a ratio of maximum to minimum diode heat input of 1.85. The minimum degradation of power and efficiency was found to be 41 and 19%, respectively, at optimized operating conditions.

5093

Ford Instrument device exploits internal pulsing, hence needs no inverters and may be step to space solar-thermionic system.

5094

Development and design of a multi-element reactor system using thermionic diodes to emit electrons from a hot surface to generate electricity. Methods for neutralizing the space charge are included.

5095
General Atomic, San Diego, Calif.
PARAMETRIC STUDY OF DIRECT CONVERSION REACTOR POWER SYSTEMS, by W.B. Wright. 133p., illus., Oct. 31, 1962. (GA-3540) (Final Tech.Rept.) (Contract Nmrr-3371(00)).

This work is composed of four major sections. In the section entitled "Models of Thermionic-cell Behavior in Reactor Systems," mathematical formulations of thermionic-cell dynamics are discussed. Energy transfer mechanisms are considered in detail and cesium vapor effects are incorporated into the analytical description. In particular, an empirical correlation of cesium wetting phenomena is provided. The resulting analytical models provide methods for determining the effects of the neutronics and heat-transfer aspects of a reactor on the performance of thermionic-cell networks. In the section entitled "Nuclear Design Aspects of Water-moderated Thermionic Reactors," two of the major neutronics problems that arise in the design of in-pile thermionic systems are examined—power flattening and lattice heterogeneity. Parametric studies of the lattice heterogeneity problem were made with multigroup transport theory. In addition, an extensive study of power-flattening methods in water-moderated high-power-density systems is discussed.

In the section entitled "The Conceptual Design of a 1-Mw(e) Thermionic Reactor System," a complete design study was made of an in-pile thermionic reactor. The interrelated thermionic-neutronic-heat-transfer characteristics of this specific system were studied using the analytical models of thermionic-network behavior. Comparison of this type of reactor with a conventional power plant is discussed. In the section entitled "Analysis of Thermionic Reactor System Performance," the kinetic behavior of thermionic reactor systems is considered. A complete mathematical formulation of the kinetics of an entire thermionic plant is developed. The resulting set of equations and the linearization of these equations are discussed.

5096

A study made here by General Electric Co. scientists indicates that an experimental solar thermionic power system, operating at about 5% efficiency with a 55-watt output, could be placed in orbit within two to two and one-half years.

5097

A unique power system for space, submarine propulsion, and applications in remote areas should result from the successful coupling of nuclear reactors with thermionic converters. Three conceptual designs of thermionic nuclear reactors are reviewed to establish requirements for performance characteristics and materials and to pinpoint some of the problem areas.

5098
Martin Marietta Corp., Baltimore, Md.
FEASIBILITY STUDY OF WATER-COOLED THERMIONIC NUCLEAR POWER PLANT. 199p., Nov. 1962. (MN-29053 (Vol. I)).
This volume contains a justification, description, and evaluation of a water-cooled thermionic plant. A series of appendices is included which describes in detail fuel element geometry, thermionic diode analysis, system control analysis, reliability and maintainability of this plant, and transportability of this plant.

5099
Martin Marietta Corp., Aerospace Division, Baltimore, Md.

A summary of research and development in the field of vacuum-diode thermionic energy conversion as it applies to radioisotope-fueled power systems is presented. The development work was done to improve diode performance, to decrease generator weight and size, to develop a radioisotope-fueled generator, and to develop a generator which can withstand missile launch. A generator which can withstand missile launch was developed during the period. A vacuum converter fueled with a radioisotope was developed which provides 2 watts for use in missile applications in space. It is noted that most of the developments associated with the vacuum diode generator are applicable in the Cs generator which is under development. (Nuclear Sci. Abs., 17:4357, Feb. 15, 1963).

5100

A discussion is presented of the fabrication and performance of a 5-ft solar concentrator, fabrication and test of 40 SET thermionic converters, and the fabrication of 2 SET thermionic generators, along with test data using both solar radiation and electron bombardment heaters. A system efficiency of 3 percent and a specific weight of 2 watts/lb was demonstrated in the first prototype system test using solar radiation. (STAR 1:15, Jan. 8, 1963).

5101


The investigation was performed by means of an experimental tube filled with cesium vapor and containing a Ta strip cathode and a similar cesium-coated Ta anode with screening electrodes, the distance between which could be varied. The investigated oscillations were recorded by an oscillogram. The variable parameters of the investigation were: cathode temperature, cesium vapor saturation temperature and interelectrode distance. The data presented give a characterization of certain new aspects of a thermoelectronic energy converter with cesium vapor.

5102
Pratt and Whitney Aircraft, East Hartford, Conn.

Parametric system studies of a thermionic reactor space powerplant with an output of one megawatt electric and an operational lifetime of 10,000 full power hours, have been completed. System specific weight has been found to minimize at a particular cathode temperature for a given fuel evaporation rate limit. Minimum system weights are defined at cathode temperatures of 3200 - 3500°F for evaporation rates of 0.002 - 0.020 inch per year in vacuum, respectively. Corresponding system specific weights for lithium-cooled systems with a beryllium radiator are 10.5 and 6.9 pounds per kilowatt.

5103
Thompson Ramo Wooldridge Inc., Cleveland, Ohio.

This report contains a state-of-the-art survey of all components required for solar thermionic power systems in the 1-10 KW range suitable for application in aerospace vehicles. The results of the survey and development program were used in a comprehensive parametric study to determine design criteria applicable to these systems. The development program included evaluation of thermionic converters of the vacuum and vapor type. The details of the design, fabrication, performance tests, and evaluation of thermionic converters and generators built during the program are presented.
This report describes the work accomplished under an applied research program directed toward increasing the cycle life of thermionic converters which can be used in solar thermionic generators. The results of cycle life tests of five thermionic converters, and the results of a solar test of a cavity-type thermionic generator which used five converters identical to the life test converters, are presented. A complete discussion of all specialized equipment and techniques is also included along with design details.


State-of-the-art performance of laboratory converters is summarized in terms of output, efficiency, and life. Results of comparative analyses are presented for several combinations of thermionic converters with nuclear heat sources. These demonstrate the superior potential of the nuclear thermionic system in which the thermionic converters are integral with the nuclear fuel element. The particular merits of the cesiated refractory metal converters for this use are emphasized. (Astron. Info. Abs., 7:70, 477, Feb. 1963).

IV. PHOTOELECTRIC PROCESSES
A. Photovoltaic
1. Theory


In English. A photoelement Au[-Ag2S]Al was made from a thin Ag2S layer on a glass sheet. Au and Al electrodes were evaporated in vacuum onto the Ag2S layer. The resistance of the element was 6 X 10^4 to 10^5 ohms, the e.m.f. was 80-250 mv, in the darkness, and the current 0.01-0.1 uamp., with Al as anode. In light, the e.m.f. initially dropped and then rose slowly to maximum 300 mv, restoring its original value obtained in darkness. These effects were more pronounced with infrared light than with light of shorter wavelengths. In darkness a galvanic e.m.f. was produced to which a photo-e.m.f. was added in the light. (Chem. Abs., 58:1018, Jan. 21, 1963).


The effect of both electron and proton irradiation of silicon photovoltaic cells is given in terms of the loss of photovoltaic response and the decrease in the lifetime. Analysis of the spectral response shows that a simple carrier diffusion model provides an adequate description of the behavior of the shallow-diffused junctions that were investigated, and yields values for the minority carrier diffusion length before and after irradiation. Most of the photovoltaic response is shown to occur in the base region of the cells, rather than in the surface layer, and virtually all of the loss of response is caused by defects introduced in the base. The reciprocal of the lifetime is linear with the cumulative irradiation flux, and is consistent with the loss of photovoltaic response. There are significant differences between p on n and n on p cells under electron bombardment; the former damaging roughly 100 times as rapidly as the latter. Under proton bombardment the difference is roughly a factor of three. A comparison of electron, proton, and neutron irradiation suggests that the individual lattice displacements produced in electron irradiation are no more effective in producing recombination than the displacements produced in high concentration in neutron and proton irradiation.

Analysis of the energy conversion in solar cells, from the incident light to power consumed in the external load. The process is split into three independent phases: (1) energy transfer from photons to hole-electron pairs; (2) photoelectric minority carrier collection at the depletion layer; and (3) energy transfer from the collected minority carriers to the external load. In addition, the most important properties of silicon cells are reviewed from the viewpoint of space communications applications.

The basic principles of conversion of sunlight into electrical energy in a semiconductor p-n junction are described. From the theory, prediction of the expected performance as a function of external and internal parameters is made, and the maximum efficiency for a number of likely semiconductors quoted. Practical results are given for typical arrangements, including space projects already successful and proposed for the future. The effects of the space environment on performance and life are discussed. Finally, the direction and promise of future developments are indicated.

The properties of CdTe films vacuum-evaporated at an oblique angle of incidence onto a substrate of glass, which are known to exhibit unusually high photovoltages, are experimentally studied. (1) The angular distribution of the intensity of light scattered by the film is asymmetric. (2) The (111) planes of the crystallites do not lie parallel to the substrate surface, as they do in the case of normal incidence. The incline of the (111) planes is determined in the main by the angle of incidence of vapor. (3) The photovoltage V exhibits a peculiar dependence on θ. It changes its sign at a certain value of θ, which in turn is determined by the substrate temperature. A model is proposed for the structure of the film, which will explain the experimental results.

The conversion of helioenergetics into an independent and important technological field is discussed. Outstanding scientists of the world, including Frederic Joliot-Curie, feel that helioenergetics will be put on an equal footing with the study of atomic energy. In this connection scientists await further research. (TAB U63-1-2:26, Jan.15,1963).

Certain crystals of ZnS generate voltages greater than the band gap voltage when illuminated with ultraviolet light. This phenomenon is called the anomalous photovoltaic effect. The purpose of this study was to devise and justify a model (semi-quantitative) to account for the general features of the anomalous photovoltaic effect.

It has been found that the presence of adsorbed oxygen increases both the response and the response time for the photovoltaic effect in rutile. The model for the effect of chemisorbed oxygen on the photocconductivity has been modified to take into consideration the effect of oxygen pressure. The conductance of rutile has been measured as a function of oxygen pressure. The results agree with the modified model. The increase in photovoltaic response and response time with exposure to oxygen has been explained in terms of the barrier layer formed by chemisorbed oxygen.

The ultraviolet photovoltaic response of
barrier-layer cells formed from single-crystal rutile has been investigated. Typical samples have response maxima at 3200 A, a D* of $10^9$ cm $^2$/s/w, and time constants of 100 µsec. Variations in time constant over several orders of magnitude have been observed; they depend largely on preparation techniques. The effect of surface treatment on cell characteristics is discussed.

5116

A theoretical investigation has been made to determine the exact role which the internal series resistance and the surface layer (p or n layer) resistance play in determining the conversion efficiency in solar energy converters using p-n junction photovoltaic cells. An equivalent circuit of the photovoltaic solar cell which is represented by a network consisting of a large number of current sources inter-connected through series resistors, simulating the effect of sheet resistance of the surface layer, is assumed.

5117

Caesium is evaporated on to a graphite plate in vacuo to form an "interstitial" compound. Illumination of the graphite on the face obscured from the cell anode still gives a photocurrent and with a more elaborate cell it is found that electrons produced by illumination pass through the graphite before being emitted and collected at the anode. (Phys.Abs.,65:12546, Jly.1962).

2. Silicon Cells

5118

The construction, operation, and performance characteristics of solar cells are described. The radiation-damage process is discussed, and details of proton and electron damage to silicon cells presented. The degradation of the photovoltaic current-voltage characteristics and the spectral response is shown, and a comparison made of various types of solar cells, including silicon, gallium arsenide, and cadmium sulfide. Differences between p/n and n/p silicon cells are discussed and explained in terms of basic properties of the radiation defects. (Sci.E Tech. Aerospace Rept., 1:NE3-15125, June 8,1963).

5119

A series of theoretical calculations have been performed concerning inelastic nuclear interactions between incident high energy protons and silicon. The results of these calculations, indicate that, above incident proton energies of about 20 Mev, the primary defect production mechanism is inelastic nuclear interactions. Additional evidence is presented which indicates that the defect structures produced by these inelastic nuclear interactions are significantly more complicated than those produced by electron and lower energy proton induced elastic nuclear interactions. Based on these phenomena, it is shown that high energy proton experimental damage data on silicon photovoltaic devices obtained at low illumination intensities cannot be applied directly to spacecraft photovoltaic power supply systems designed to operate at the illumination levels existing in space. (STAR, 1:14, Jan.8,1963).

5120

The feasibility of producing radiation-resistant silicon solar cells by the use of a graded base structure is being studied. Methods of fabrication of both n on p and p on n graded base cells are discussed and the results of efficiency measurements at sea level and on Table Mountain are presented. The results of bombarding the cells with 1-Mev electrons are shown and compared with the results obtained by bombarding n on p cells having a uniform base region of 25 ohm cm resistivity. The results of experiments designed to measure the presence of an electric field in the base region of the graded base cells by carrier transient time measurements are given. The results indicated that the graded base structure affects the transport properties of minority carriers injected.
into the base region of the cells. The electron irradiation experiments also indicated that the performance of the cells when subjected to 1-Mev electron bombardment is at least as good and may be superior to that reported on other silicon cells. (Nuclear Sci. Abs., 17: 6795, Mar. 15, 1963).


In Japanese. In the case of Si batteries of large area, the flow of the generated current through the thin P-type layer causes voltage drop and power loss before reaching the terminal electrode, so that a distributed-constant equivalent circuit is required for analysis. Discussion of such a circuit leads to a nonlinear differential equation for the potential distribution of the solar cell, a solution of which has been obtained by use of a computer and an approximated equation. Expressions are thus derived for the potential distribution on the P layer, the generated power, the internal power loss caused by the series resistance, and the output power of both rectangular and circular Si solar cells. (Elec. Eng. Abs., 65:14673, Dec. 1962).

Experiments have been performed to study the defects introduced into silicon by high energy (-30 Mev) electron irradiation. These defects are expected to be similar to those produced by high-energy protons. The diagnostic tools used include measurements of galvanomagnetic coefficients, excess carrier lifetime, electron-spin resonance, and infrared absorption. The results indicate that the A center in quartz-crucible-grown silicon is not the primary excess-carrier recombination center. Instead recombination in quartz-crucible-grown and floating-zone refined silicon appears to be dominated by the same center.
particles is considerably enhanced. (STAR, 1:16, Jan.8, 1963).

5127

An analytic expression for the decrease in efficiency of a solar cell, behind a protective cover glass, exposed to a spectral distribution of protons is formulated on the basis that the time rate of decrease in output power is proportional to the proton dose rate absorbed at the surface of the solar cell. The decrease in the maximum power output of an n-on-p silicon solar cell exposed to the solar flare of 12 November 1960 is calculated as a function of the thickness of protective cover glass for a power-law representation of the differential flux spectrum of the incident protons. (Sci. & Tech. Aerospace Rept., 1:N63-15128, June 8, 1963).

5128

The objectives of the contract are to further investigate the possibilities of solar energy conversion utilizing the photovoltaic effect in polycrystalline silicon layers and to apply the results of the investigation by devising methods and techniques applicable to the fabrication of low cost, large area solar cells.

5129

Surface photovoltage measurements were employed to test the effects of electrolytic environment on both n- and p-type silicon having a range of resistivity values. The electrolytes chosen were those used in various phases of the chemical processing of silicon for commercial use.

5130

The Hall coefficient and conductivity have been measured during pile irradiation for a number of zone-refined p-type silicon crystals with initial resistivities of 1, 8, and 100 ohm-cm. To supply the magnetic field (500 oersteds) for the Hall measurements in the reactor, a small electromagnet was used. The conductivity of zone-refined silicon shows much faster changes with irradiation than pulled silicon samples of equivalent resistivity. The 100-ohm-cm samples exhibit a monotonic nonlinear decrease of \( \ln \sigma \) (conductivity) vs \( \Phi \) (integrated fast flux), whereas the other samples with initial Fermi levels closer to the valence band have one or two regions of linear decrease in \( \ln \sigma \) vs \( \Phi \) before the nonlinear decrease region is observed. The Hall mobility for the 100-ohm-cm samples decreases and becomes negative as a result of the carrier density decreasing with irradiation. In the case of the 1-ohm-cm sample, the Hall mobility decreases with irradiation, whereas the 1-ohm-cm sample shows no change in Hall mobility with irradiation up to the maximum integrated flux used in the present experiment. The origins of the dependence of \( \ln \sigma \) on \( \Phi \) as well as the behavior of the Hall coefficient and Hall mobility with irradiation are discussed.

5131

As a result of the high-altitude nuclear explosion over Johnston Island, an intense electron radiation belt has been trapped in the earth's magnetic field. This belt can cause silicon solar cells to deteriorate at a much greater rate than was previously expected as a result of protons in the natural Van Allen Radiation belt. At the altitudes of instrumented satellites, the electron radiation belt does not appear to be diminishing at a rate fast enough to offer relief from this new environment in the near future. To provide a satellite solar-cell power-system with a long-life capability, it will be necessary to provide a large margin of over-design in the initial power-generating capability of the solar power system. The use of N-on-P solar cells will have a significant effect in increasing the life of the satellite's power-generating system. The use of thick cover slides for the solar cells will result in a decrease in the rate of degradation. The extent of this protection cannot be accurately determined until the energy spectrum of the trapped particles is better defined. Direct measurements of the effectiveness of various shield thicknesses are being obtained from the ANNA satellite.

Results are presented of a study of various radiation-induced changes in the electrical, optical, and magnetic properties of n- and p-type silicon. Lifetime measurements show a number of different radiation-induced recombination levels. Trapping measurements show a large number of minority carrier traps produced by bombardment. A summary of observations of thermally stimulated conductivity in normal and neutron-irradiated silicon is given. A number of solar cells of both Si and GaAs were irradiated with electrons and protons. The damage rate with electron energy between 0.8 and 5.6 MeV is reported for p-type silicon (n/p solar cells).


The effect of radiation damage on the important parameters of solar cells has been evaluated for groups of blue-sensitive n-on-p, normal p-on-n, and blue-sensitive p-on-n cells using 1-Mev electrons. The outer space short circuit current, maximum power, junction characteristic, and spectral response are presented quantitatively as a function of radiation flux along with the bulk minority-carrier diffusion length.


A short discussion of semiconductor P-N junctions is given. This will be related to the operation of a photovoltaic device. A method of fabricating a silicon photovoltaic energy conversion device is discussed. Considerations of spectral response and optimization to solar radiation resulting in the development of a solar simulator are described. Special requirements of solar cells operating in earth space are mentioned. (Nuclear Sci.Abs., 17:655., Mar.15,1963).


Radiation damage to solar cells is discussed.
solar simulator provides a light source similar to the sun and a space environment for testing solar cells. Measurements were also made during irradiation using floodlamps as a light source. The results indicate that deuterons are more damaging than protons by a factor of 3 to 5, and gallium arsenide cells are more resistant to radiation than Si solar cells.


Several types of silicon solar cells have been irradiated with approximately 4.8 Mev protons. Variations in the cells irradiated in the experiment were bulk material, impurity concentration, and oxygen concentration. Changes in diffusion length, spectral response, and current-voltage characteristics show that the n/p cell is more radiation resistant than the p/n. No difference in radiation resistance is seen by varying the oxygen concentration, but there is a trend toward increased radiation resistance as the resistivity of the bulk is increased.

3. Compound Semiconductors


This report summarizes two years of effort directed toward the development of new materials for photovoltaic solar energy conversion. A brief review is given of the factors governing the selection of materials for efficient solar cells.


Substantial contract effort was devoted to improving the conversion efficiency and learning as much as possible about the variations in the fabrication and the overall performance of polycrystalline vapor-reacted thin film solar cells. Solar conversion efficiencies up to 6% have been achieved in polycrystalline film cells with some samples exhibiting open circuit voltages up to .55 volts and other samples showing short circuit current densities about 18 ma/cm², these values at room temperature under 80 mw/cm² solar irradiation. Various performance data on polycrystalline film cells are presented in this report. Included are spectral response, load characteristics, illumination dependence, temperature dependence, etc. The single crystal results which are also presented offer considerable encouragement for the applicability and general utility of the solar cell fabrication technique developed during this year's program with vapor reacted films.


The p-n junction photovoltaic effect in Zn-doped GaP was studied as a function of various parameters. The spectral sensitivity, the temperature dependence of the short-circuit current and the open-circuit voltage are discussed. In addition to the intrinsic effect an extrinsic photovoltaic effect was found. Arguments are given to show that the extrinsic response is not an electrode effect, but is clearly correlated with the specific dope introduced into the GaP bulk.


In Russian. Transl. in Electron. Express, 5:9, 8-9, 1963.

Gallium arsenide photovoltaics are described that have an efficiency of ~7% and do not require a coating that reduces reflection.


Gallium arsenide photocells with efficiencies of approximately 7%, not requiring the use of antireflection coating, are described.


The method of preparing GaAs photocells is briefly described. The following properties are reported and analyzed:
spectra of photocells and current-voltage characteristics of p-n junctions under photocell and diode operating conditions at various temperatures; temperature dependences of the short-circuit photocurrent and photo-emf at various intensities of illumination; and the relaxation characteristics of p-n junctions under photocell and photodiode conditions for various intensities of light and various temperatures.

5147
Harshaw Chemical Co., Cleveland, Ohio.


As the result of Contract AF33(616)-7528, the CdS front wall evaporated film solar cell progressed to the point where large area cells of 9 square inches could be made in the range of 2 to 3% conversion efficiency with reasonable reproducibility. Testing of the CdS film cell under the conditions of space and the conditions that would be encountered in getting arrays into space is the principal objective of the present contract. Secondary objectives are to improve the performance of the CdS film cell and to obtain a better understanding of the fundamentals governing the operation of this cell.

5148
Harshaw Chemical Co., Cleveland, Ohio.


During this period an evaporator was tooled for the purpose of evaporating uniform CdS films on 6" x 6" substrates. Several large area films were made, some of which were completed as front wall photovoltaic cells. Two hundred fifty-eight cells were produced on the pilot line with an average efficiency of 2.06% and a maximum efficiency of 3.5%.

5149
Harshaw Chemical Co., Cleveland, Ohio.


During the past quarter Cu5Se2 and Cu2S have been synthesized and examined. Large CdTe crystals have been grown by vapor phase deposition and found to have unusual metallic precipitate on them. Films of CdTe containing various dopants have been prepared by coevaporation and examined for resistivity as a function of temperature. The recrystallization of CdTe by dendritic growth during film formation by coevaporation has been observed. The effect of polytypism upon the etching behavior of II-VI compounds has been examined. CdSe solar cells have been prepared from CdSe films containing various dopants.

5150
Harshaw Chemical Co., Cleveland, Ohio.


Continued development of a thin-film solar cell using vacuum-evaporated layers of CdS is summarized. Primary emphasis was on the front wall CdS film cell using molybdenum foil substrates. Efficiencies of large-area (up to 9 sq. in.) front wall cells were increased to the range of 2 to 3%. The major factor in this increase was the reduction of sheet resistance by the use of a fine-mesh metallic grid laminated to the barrier surface. Improved vacuum evaporation techniques made possible a reduction in CdS film thickness and in molybdenum foil substrate thickness, each to about 0.001 in. With these improvements, power-to-weight ratios for CdS thin film front wall solar cell arrays, that may be suitable for space applications, of 20 to 30 watts/lb seem assured. Some tests of CdS front wall film cells and arrays indicate that they should be stable in the high vacuum of space, and possibly fairly resistant to radiation of the Van Allen types. Research studies on the structure of CdS single crystals and polycrystalline films continued regarding grain growth, orientation and polarity effects, etching, and grain boundary studies. There are indications of a correlation between crystallite orientation and photovoltaic response. (TAB U63-2-3:17, May 1,1963).

5151


The results of a study of electrical and photoelectric properties are reported for sublimated crystalline layers of antimony triselenide, in which photo-emf’s up to 50-80 V/cm were generated on
illumination. In addition parameters are given for layers of some chalcogenides of antimony and bismuth in which high-voltage photo-emf's were also observed.

5152
National Cash Register Co., Dayton, Ohio.

Studies included: possible variations in the physical structure (crystallinity and crystallite orientation) of the semiconducting layer (CdS and CdSe) due to changes in the deposition parameters; the effect on different orientations due to heat treatment; changes in resistivity due to heat treat and doping; improvement of the deposition of the barrier layer; investigation of a barrier layer using copper selenide; search for a flexible (metal foil) substrate compatible with the film deposition conditions; investigation of the possible correlation between crystallite orientation and crystallinity to photovoltaic response; and the spectral characteristics of the CdSe, CdS, and CdSe-CdS photovoltaic cells. (TAB U63-1-4:29-30, Feb.15, 1963).

5153
Radio Corp. America, Defense Electronic Products, Princeton, N.J.

Effort was made to determine the technology necessary for the application of a high-temperature, radiation-resistant array of solar cells in a configuration suitable to aerospace vehicles. Toward this end, gallium arsenide solar cells are being fabricated for temperature and radiation tests, and experimental studies are being conducted to determine techniques for fabricating modules and arrays. In the second report, Progress is reported on GaAs cell development and fabrication for temperature, radiation, and array configuration testing. (TAB U63-1-4:5:131, Dec. 1, 1962. & TAB U63-1-3:20-21, Feb. 1, 1963).

5154
Radio Corp. America, Semiconductor and Materials Division, Somerville, N.J.

A discussion of solar cell fabrication is presented; the discussion includes commentary on: (1) crystal used and crystal properties; (2) diffusion techniques used; (3) surface treatments used; (4) a comparison of Polystylene and silicon oxide antireflecting coatings; (5) data for n on p cells; (6) diffusion techniques for formation of gallium phosphide on gallium arsenide substrates; (7) methods for growing large area gallium arsenide single crystals; and (8) methods for epitaxial growing of gallium arsenide layers from the vapor phase. Experimental procedures employed are outlined and several analytical investigations are presented concerning optimum grid structure, solar cells with cascaded energy gaps, the effect of the built-in field, surface recombination, the optimum antireflecting coating, and the determination of short-circuit current from the spectral response curve.

5155
Radio Corp. of America, Somerville, N.J.

In order to facilitate fabrication of solar cells for initial process experiments, the fabrication process developed under contract NASS-4S7 and presently in use for contract AF 33(657)-8490 was adopted. The present process resulted in typical efficiencies between 6 and 8% with maximum efficiencies near 10%. Cells now being made with GaAs are doped with either Ge or Si. An experiment performed to evaluate fabrication procedures indicates that the use of a tungsten light for optimization of cell efficiency by etching will result in an optimized cell for sunlight. (TAB U63-1-2:23, Jan. 15, 1963).

5156
Shirland, F.A., Griffin, T.A. and Bierssen, G.H.

A new photovoltaic cell made from a film of CdS vacuum evaporated onto a metal foil substrate is described. Such cells are being made in sizes up to 3-in x 3-in, at conversion efficiencies of 2 to 3%. They can be laminated in plastic envelopes.
to form arrays delivering 10 to 15 watts per pound. It is estimated that these cells can be made very economically. Typical I-V characteristic, spectral response, and temperature performance curves are given. Data on the stability of these front wall CdS cells, including resistance to radiation damage, are also presented. Possibilities for larger area, lighter weight, higher efficiency cells of this design are discussed. (STAR, 1:16, Jan.8,1963).


The dependence of the spectral characteristics of the photovoltaic and photocurrent effects on the concentration of impurity centers and the degree of their compensation was studied in specimens of Ge:Au:Sb and Ge:Zn:Sb. The temperature dependence of the photosensitivity was also studied. It is shown that the photovoltaic effect is independent of the impurity concentration and the degree of compensation while the photocurrent effect depends on the ratio Nd/Na. For each specimen with a specific type of impurity center there is a limiting temperature above which the photosensitivity drops abruptly.


Surface photovoltaic measurements on conducting crystals of cadmium sulphide show that, at equilibrium, there is a difference in potential between the surface and the bulk of 0.2 to 0.3 eV. This is due to adsorbed oxygen which forms charged acceptor states on the surface. The adsorption is a reversible process, and the oxygen may be removed by replacing the air ambient with an inert gas such as nitrogen. The density of charged surface states on typical conducting crystals is $1 \times 10^{11}$ per cm$^2$. On high-resistance photoconducting crystals there is no detectable density of charged surface states. There is, however, a measurable photovoltage which is apparently due to the Dember effect. A model is proposed for the surface states which accounts for the observed behaviour. (Phys.Abs., 65:21190, Nov.1962).

4. Devices


Standard switching circuitry as well as a new gating circuit for solar-cell hole readers are described. Both are treated in terms of the movement of their operating points on the solar-cell characteristic curves. The typical circuit for a solar cell controlling a transistor in a card reading operation is shown. When the cell is off, the transistor is biased "on" through a resistance. When the light comes through a hole to turn the solar cell on, the cell generates enough opposite polarity voltage to remove the "on" bias from the base of the transistor. Often the output of these transistor amplifiers must be gated. For each solar cell circuit two additional diodes are usually required. A better method for gating solar cells employing a resistor and common gate transistor driver which minimizes the cost of such gating is described. (Info. Processing J.,1: 2084, 1962).

Clevite Corp., Electronic Research Division, Cleveland, Ohio.


The first report gives a description of work done on cadmium sulfide solar cells prior to the present contract by the Electronic Research Division of Clevite Corporation. This is followed by a discussion of the necessary requirements for "scaling-up" equipment and processes in order to accommodate the larger solar cells to be investigated under the present contract. Then specific experiments to determine optimum parameters are described followed by a brief discussion of alternate methods of producing cadmium sulfide solar cells. Finally, the present status of semiconductor photovoltaic theory applicable to cadmium sulfide solar cells is discussed. The second reports that a total of twenty-two evaporations have been performed, twelve being completed in the second quarter and yielding a total of 146 film samples ranging in size from 4 x 4 inches to 1 x 1 inch. Improvements in processing of samples are described and data are tabulated to show how the average conversion efficiency has been raised from one-half percent to two percent as more parameters are identified and controlled. Spectral transmission curves are also given for evaporated CdS films showing the effect on optical transmission of the barrier layer formed by the cuprous oxide slurry.

An x-ray detector in which the basis of operation is a p-n junction, silicon solar cell is described. When such a cell is bombarded by x-rays, hole-electron pairs are liberated, some of which become separated by the electric field existing at the junction and are responsible for the generation of a voltage at the terminals of the device. The power available from the cell is proportional to the junction area, so that by using a large area cell the degree of subsequent amplification required can be minimized. The radiation damage threshold for silicon is -0.3 MeV, so that deterioration of the cell characteristics for normal diagnostic operation of the x-ray tube presents no problem. Measurements of the cell characteristics before and after being subjected to a total radiation dose of 6000 r (at 100 kv) showed no detectable change. Since output from the cell used was inadequate, a transistor differential preamplifier was used. The x-ray monitor enables an output to be obtained that is a measure of the x-ray voltage and current. However, if an output is required that is independent of these factors, the amplifier can be followed by a simple transistor limiter to yield a constant output. The complete device can be assembled for less than $25.

(Columbia University, School of Engineering and Applied Science, New York, N.Y.


Theory, experimental apparatus, and experimental results are described for radiation measurements from the ultraviolet to the infrared (2000 A to 14,000 A), and energy conversion using semiconductor solar cells. This work is part of the National Science Foundation new laboratory-equipment-development project to improve laboratory demonstration experiments. (Sci. Tech. Aerospace Rept., 1:N63-14942, June 8,1963).

Eagle-Picher Co., Chemicals and Metals Division, Miami, Oklahoma.


The general objective of this Contract is to investigate the variable band gap structure GaAs_x-GaP_y-x, having a gallium phosphide surface grading to lower energy gap GaAs below the surface and containing a single junction.

Great Britain, Royal Aircraft Establishment, Farnborough.


Various possible ways of increasing the output power are examined, all of which involve accepting less incident radiation. The only practical scheme is to reflect quanta of wavelengths longer than the threshold for silicon (1.1 μ) which might increase the output power by about 10%. Some further, but very small, increase might be achieved by reflecting high energy quanta of wavelengths shorter than about 0.35 μ.

Gummel, H.K., Saits, F.M. and Froiland A.R.


A procedure for predicting the output short circuit current of solar cells is presented. This procedure is similar to, and utilizes, the well-established method of the Smithsonian Institution for the determination of the solar constant. The only absolute calibration used is that of a current meter. It is demonstrated that accuracies of 2% can be achieved with relative ease.

Hanson, K.L.


Major problem areas in predicting the output of photovoltaic power supplies for space vehicles are identified. The accuracy requirements are defined, and present methods of prediction are described and evaluated with respect to the requirements. It is concluded that refinement of present methods will be sufficient for future needs, but correlation and additional high-altitude experimentation are needed. (Nuclear Sci. Abs., 17:9104, Mar. 31, 1963)

Hoffman Electronics Corp., Hoffman Semiconductor Division, El Monte, Calif.

SOLAR ENERGY MEASUREMENT TECHNIQUES,

This report describes a broad investigation which has been made of the subject of solar-cell measurements. A portable tester has been designed and built which will enable an operator to determine the output of a solar-cell power supply in space by analyzing output under conditions existing at either laboratory or field test sites. (STAR, 1:N63-16269, Jly.8,1963).

5168

The transmitter-receiver equipment, which has an average consumption of 4.5 W, is supplied by NiCd cells charged from solar batteries with a peak output of 70 W. (Electron.Tech.39:A97, June 1962).

5169

Resistive losses in solar cells become quite large for high incident flux levels. A method is described, consisting in the addition of a grid-structure contact to the top surface of the cell, for reducing these losses in regions where the incident intensity is 1 w/cm² or more. The grid dimensions are determined by the anticipated flux level. This method is shown to be capable of increasing the efficiency of a solar cell, at 1 w/cm² incident intensity, from about 50% to about 97% of the theoretical power output. (Nuclear Sci. Abs.,17:9115, Mar.31,1963).

5170

This paper contains a review of recent work on photovoltaic cells fabricated from semiconductors other than silicon; the effects of radiation on silicon n/p and p/n cells, and gallium arsenide p/n cells; and thin film photovoltaic cells.

5171

The power output of a solar cell panel can be increased by the use of auxiliary reflectors or other types of optical concentrating devices. The use of concentration with solar cell systems is discussed and is contrasted with the situation for high temperature solar power converters involving heat engines. Theoretical performance and weight estimates are given for various configurations of concentrating photovoltaic systems. Design and selection of components and materials are discussed, including cells, cell panels, concentrators, filters, and coatings. A 50-watt ground test model is described and experimental performance results are given. (Nuclear Sci.Abs., 17:9125, Mar.31,1963).

5172

Relationships are reviewed between the essential parameters of solar-cell performance and the changes in cell temperature, incident illumination, and solar-energy spectrum as one goes from lab conditions to space. A method is given for constructing nomographs for conversions from sea level characteristics to determine cell performance in spacecraft.

5173

Work during the quarter was directed toward chemical surface treatments and their efforts on breakdown voltages, studies on the formation of thermal oxides of silicon, and the electrical evaluation of passivating coatings on silicon.

5174

Research of photovoltaic materials has shown the feasibility of fabricating cells with the p-n junction far removed from the surface by means of heterogeneous cell formation, of fabricating cells by
the silk-screen technique of applying the active material, and also has shown that CdS polycrystalline cells are more resistant to 1.6 Mev protons and to 0.8 Mev electrons than are n-on-p silicon cells. Five cells of small area were fabricated and demonstrated the feasibility of making cells from converted CdS layers. The maximum efficiency of these cells was about 0.7%. (TAB U63-2-3:17-18, May 1, 1963).

5175
Radio Corp. of America, David Sarnoff Research Center, Princeton, N.J.

In the first report methods are described for the production of n-type and p-type films of gallium arsenide on tungsten and molybdenum sheet. During the second quarter work was concentrated on the improvement and understanding of junction structures in gallium arsenide films. Open-circuit voltages of up to 0.7 volts have been observed on small areas. Short circuit-currents of 1 ma have been observed on larger area units. Better control of the growth of gallium phosphide films has been achieved. They show semiconducting properties, but continue to be n-type.

5176
Rappaport, P., Loferski, J.J., and Linder, E.G.

The electron voltaic effect is analyzed to show how the properties of the semiconductor (energy gap, minority carrier diffusion length, surface recombination velocity and the temperature) and of the impinging electrons (average energy, density, maximum energy) affect the usefulness of the electron-voltaic effect as a means of converting the energy of beta rays into electricity. Experiments on germanium and silicon p-n junctions are described.

5177
Spectrolab, North Hollywood, Calif.

This report is concerned with the study of spectrally selective filters for silicon solar cells used in auxiliary power systems for space vehicles. The effect of filters on array efficiency is evaluated and optimum specifications are determined for the various classes of coatings. A survey is made of state-of-the-art coatings with respect to physical properties and performance under various environmental conditions.

5178
Spectrolab, North Hollywood, Calif.

Performance analyses are made of silicon cell solar power systems using radiation concentration and filtering. The elementary conditions of system design for optimum performance of such systems are established and a plan is outlined for construction of a prototype system. Specifications for suitable mirror filters are formulated. Experimental mirror filters are fabricated and data obtained to evaluate the effect of such filters on solar power system performance.

5179
Tallent, R.J. and Oman, H.

A system employing an Archimedes array of six flat plate-glass mirrors was adopted as a concentrator to test the performance of solar cells in high intensity sunlight. Test results are given. (JPL Astron. Info. Survey 5:50,889, Apr. 1962).

5180
Wayne State University, Detroit, Mich.

A method of preparing thin films of Cu2O by an electrodeposition technique has been developed for the study of these films. The basic properties of these films differ only slightly from results on thermally prepared Cu2O except that water has been found to be incorporated in the deposit. This can be eliminated by annealing at a proper temperature. The sulfide treatment of the Cu2O surface of a copper oxide photovoltaic cell has been found to affect only slightly the output of thermally prepared cells.
Sulfiding on electrolytically prepared cells was found to increase the power output by a factor of 10^2 to 10^3. The reason for the increased output is the lowering of the series resistance of the cells by the sulfide layer and a consequent increase in the efficiency of collection of the carriers produced at the photosensitive junction. This effect is larger for high resistance electrolytic Cu_2O than for the lower resistance thermal Cu_2O. The effect of the sulfiding treatment on the photovoltaic output can be maximized by proper selection of sulfide layer thickness and geometry of the top contact.


In addition to the communications receiver and transmitter, Telstar contains several radiation experiments and a number of subsystems for acquisition and control. The power drains for the various loads are operated on different duty cycles, reaching a peak load of about 24 watts. The satellite power system design is severely constrained by requirements of long life (one to two years), minimum size and weight, and extreme radiation exposure. A solar cell, nickel-cadmium battery power system is selected, utilizing silicon n-on-p solar cells and special nickel-cadmium cells. Power conversion circuitry is designed to perform at maximum possible efficiency. The battery bus voltage variations are regulated to a common minus 16-volt bus by means of a solid-state regulator. High voltages for the traveling wave tube are obtained from this bus by means of a solid-state converter circuit. In view of the space and weight limitations, emphasis is placed on extremely reliable components and circuitry rather than on redundant systems. (Nuclear Sci.Abs., 17:9118, Mar.31,1963).

5182


A theoretical investigation into the effects of electrostatic drift fields in the diffused region and in the base region of photovoltaic solar energy converter cells has been carried out. Expressions for a single-layer and a two-layer model for each of the two regions have been evolved. These expressions have been applied to the study of the semiconductor parameters in the diffused region with and without drift field. The applicability of surface recombination velocities in the normal expected range has been established, and the introduction of a drift field in the diffused region has been found to necessitate only a decrease of the minority carrier lifetime by a factor of 4.4 compared to the field free case. Further, a study of the effect of drift fields in the base region can considerably reduce the radiation damage rate and increase the useful life of solar cells in the Van Allen belt environments by about an order of magnitude over that of present "n on p" radiation resistant silicon solar cells. Various configurations of the drift fields in the base layer, including arrangement in one and two layers with drift field, were investigated in order to find the most promising layout for the achievement of the slowest degradation rates, and to lay the groundwork for future device design work. Data for the more promising configurations are given.

5. Systems


The power system of the Telstar satellite combines the energy-converting feature of solar cells with the energy-storing capability of rechargeable batteries.

5183


The power supply system in the Telstar spacecraft consists of a solar cell plant to convert solar radiation to electrical
energy when the satellite is illuminated by the sun, a 19-cell nickel-cadmium battery to store energy, and a regulation circuit to supply constant output voltages over a wide variation in input voltages. Additionally, the power supply system provides switching to conserve power and allow battery recharging during periods between communications experiments.


The radiation experiments on the Telstar spacecraft were designed to measure the electron and proton particle distributions in the region of space explored by the satellite orbit and to give information on the integral semiconductor radiation damage produced by these particles. A solar aspect experiment is included with the radiation experiments because of its direct importance to solar cell damage results. The design and the hardware for these experiments are described in the present paper. Results of the experiments are included in a companion paper in this issue.


The feasibility of using solar cells for supplying power for the Apollo vehicle was studied and the results indicate that solar cells are the lightest and most reliable method (within the present or near-future state of the art) of producing electrical power for the anticipated Apollo mission. A preliminary design of a photovoltaic power system is presented. Structures, thermal characteristics, and electrical power are discussed in detail. The system is designed to produce an average power of 2.2 kW. The solar array consists of 276,480 cells which are mounted on 10 separate petals attached to the service module. Orientation is achieved by positioning the entire vehicle. The estimated weight is 647 lb. (Astron. Info. Abs., 6:01, 258, Nov. 1962).


Knowledge of cell characteristics and performance having recently become much more precise, the engineer can now treat system designs with greater skill and efficiency.
l-Mev normal incidence flux of \(6 \times 10^{12}\) electrons/(cm\(^2\) day). From this comparison it is estimated that the plant will degrade to 68 per cent of its initial output after two years in orbit.

5191

A description is presented of the electrical power system used in the International Ionospheric Satellite, S-51, jointly sponsored by the United Kingdom and the United States. For this cooperative effort, the British supplied the scientific experimental equipment while the Goddard Space Flight Center contributed the payload electronic instrumentation, the power supply, the satellite structure, and the ground station equipment. The satellite employs a flat solar cell configuration rather than the conventional shingled-modular type and utilizes an electrochemical cell as a one-year payload cutoff timer. Of particular note are the techniques used to obtain proper charge rate into the rechargeable nickel-cadmium batteries, the novel standby battery with automatic switching circuitry and the precision static dc to dc conversion equipment. (STAR, 1:13, Jan.8,1963).

5192

The use of high-altitude balloon flights in determining the earth space short-circuit current of solar cells is discussed. The application of balloon flight measurements to the determination of solar-cell spectral correction factors is outlined. (STAR, 1:13, Jan.8,1963).

B. Photoemissive

5193

The photoelectric emission from a nickel ribbon has been observed as a function of temperature from 25° to 760°C, over a wavelength range from 2250 to 2530 Å, qualitatively confirming and extending Cardwell’s earlier work. The yield increases with temperature at all wavelengths, with an upward bulge near the Curie point. Fowler-Dubridge analyses of the emission from the front face of the ribbon, which is found to contain mainly (111) facets after extensive outgassing, yield values of the work function ranging from about 5.07 ev at 25°C to about 5.20 ev at 760°C. Behavior below the Curie point may be consistent with the magnetization-squared dependence recently suggested by Wonsowski, et al.

5194

Differential thermal analysis of a Se photocell was carried out with an apparatus comprising two identical photocells, one acting as control, with thermocouples connected in opposition to a circuit of varying external resistance. The temperature difference between the cells was thus measured, using an amplifying galvanometer. It was found that there is a critical value of the external circuit resistance, above which, the photocell cooled to a temperature equilibrium, and, below which, its temperature increases. It is concluded that the action of light (from which infra-red radiation has been eliminated) has three effects, (1) to heat the cell, (2) to produce the photo-electric current, and (3) to modify the structure of the barrier-layer. (Inst.Metals J., 91:76, Oct.1962 & Metallurgical Abs.,50:76, 1962).

5195

The note presents measurements of the photoelectric emittance from different thicknesses of evaporated gold films.

5196

Techniques used to obtain high vacua, to provide clean surfaces, to deposit Na on these surfaces and to measure their work functions are described. A method used to fabricate hemispherical grids is also included. Work function, electron diffraction and secondary emission studies of sodium-covered germanium are presented. Preparations for a field-emission study of the same system are described. In the study of the compound Na₃Sb, preliminary data on the details of film
formation have been obtained and the inert atmosphere facility for the preparation of the bulk material has been completed. A brief description of the apparatus to be used in the study of anomalous photo-voltaic effects in Ge films is given.

5197

The characteristics of a photoemissive solar energy converter were studied. The practical form of this device is a perforated sheet of a dielectric such as polyethylene terephthalate resin coated on one side with a photoemitter and on the other with a low work function conductor. Photoelectrons emitted from the front surface by solar radiation fall back through the holes and are collected on the back surface. The resulting charge transfer builds up a potential difference which may be used to perform useful work. Models were constructed and tested in evacuated glass envelopes of ultraviolet transmitting glass using a xenon arc as a solar simulator. The observed power conversion efficiency was of the order of 10^{-3}. There was no correlation between converter efficiency and geometrical parameters. Measurements of spectral response showed good agreement with published values for CsSb. Life tests did not show any deleterious effects due to the evaporation which would be expected to occur in space. Calculation of rates of evaporation indicated a life of 0.8 year at 27°C and 70 years at 0°C. The effect of oblique incidence was found by experiment to be a decrease in output at a lower rate with respect to angle of incidence than would be predicted by the cosine law. It was found that CsSb surfaces can be formed at temperatures considerably below 120°C by a co-deposition of cesium and antimony. (STAB, 1962, Jan. 25, 1963).

5198


As a result of an electron-diffraction investigation of vacuum-deposited thin films of cadmium telluride, the following structural properties have been established: 1) well defined crystallite orientation associated with material in the molecular beam arriving at the growing crystal from a single direction; 2) the formation in the film of crystallites of variable structure - cubic and hexagonal (12h poly-type); 3) the formation within the crystallites of the hexagonal phase of a large number of stacking faults. An attempt is made to associate the generation of the high voltage emg, which is produced when the CdTe film is illuminated, with these structural properties.

5199

Experimental results dealing with the influence of Na overlayers on the photoemission and work function of Ge and Si crystals are presented. For Ge a model is presented which predicts the observed dependence of photoelectric threshold on coverage. For Si the simultaneous measurement of photoelectric threshold and work function has allowed inferences regarding the source of photoelectrons in the surface region, and the nature and degree of surface band bending. Methods of preparing bulk NaSb are discussed, and a glovebox facility required for further study is described. Progress on the study of NaSb films is summarized, and a tube for film composition control is described. A calculation of the potential variation in the surface space-charge region of an intrinsic semiconductor is given.

5200
Westinghouse Electric Corp., Electronic Tube Division, Elmina, N.Y.

Studies and investigations on high temperature photovoltaic techniques and materials were directed toward making available a means of sensing light for photo-sensitive devices operating in environments up to 120°C. A Na-K-Si photoemissive cathode was developed which can withstand elevated temperatures in excess of 120°C for an extended period of time combined with high sensitivity and uniformity over the useful photocathode area. Photocathode cells were prepared and measured for sensitivity spectral response and resistivity.
5201

An experimental cyclone furnace for studying high-temperature combustion of pulverized coal with oxygen-enriched air and seeded with alkaline salts is described. Temperatures of 4000°F and higher will be attempted. The objectives of the study are to determine the nature and disposition of the slag deposits downstream from the furnace, extent of corrosion of various boiler-tube materials at wall temperatures of 500 to 1700°F on exposure to the highly alkaline products of combustion, and the distribution and possible recovery of the seeding material. (Nuclear Sci. Abs., 17:8302, Mar. 31, 1963).

5202

Review of progress in MID power generation at the Avco-Everett Research Laboratory. The work is part of a program to determine the suitability of MID for central-station power generation. Detailed consideration is given to the oxygen cycle and the electrical conductivity of seeded combustion products. (Intern. Aerospace Abs., 3: A63-14035, May 19, 1963).

5203

The results of recent research and engineering, including a high-strength superconducting magnet, have been utilized to design a 500-megawatt MID-steam turbine combined-cycle electric-power generating plant. Wherever possible, presently available materials and standard practices have been utilized to give close approximation to such a plant as it might be designed and constructed in the near future. Performance calculations show the incentive behind the present efforts being expended in anticipation of the solution of the remaining problems. The capital costs presented for such a plant, while not discouraging, include areas of appreciable ignorance. The actual costs in these areas require better definition to confirm the attractiveness of the MID principle for the central-station application. The overall economics of MID-steam turbine combined-cycle power-generating plants is compared with the moving target of today's cycles: fossil-fueled steam turbine, fossil-fueled steam and gas turbine combined cycle, and finally, nuclear-fueled steam turbine. This comparison emphasizes the urgency of successfully solving the present MID problems even if the MID principle is to find wide use in electric utility central stations. (Sci. & Tech. Aerospace Rept., 1:N63-14318, May 23, 1963).

5204

The various possible systems of a.c. magnetohydrodynamic power generation using electrodes or inductive coupling with stationary or alternating magnetic fields are examined and compared with the d.c. case. It is shown that with gas temperatures below 3000°K and an alternating magnetic field the cost of coil driving equipment is likely to be prohibitive, whilst theoretical and experimental evidence suggests that with inductive coupling and a steady magnetic field the power densities are probably too low to be of interest. The only possibility remaining is the generator with pulsed conductivity where the current is collected on electrodes and the considerable difficulties peculiar to this method are discussed.

5205

Eddy-current or end-loop losses in a magnetohydrodynamic generator are studied, taking the Hall effect into consideration. Equations are derived for a steady two-dimensional electric field in a plane perpendicular to the applied magnetic field of a constant-area duct, assuming that the magnetic Reynolds number is small. By use of the derived equations, the region around the electrode ends of the MID generator channel is investigated. The end losses are found to increase very rapidly with a, the ratio of the Hall voltage to the ohmic voltage, if continuous electrodes are used. Electrode
segmentation increases the power density and reduces the relative end losses. Graphs of current paths and potential lines are presented for continuous electrodes with and without Hall effects. (Nuclear Sci. Abs., 17:9087, Mar. 31, 1963).

5206

The major progress made during the last quarter was the verification of magnetically induced ionization by means of the cinespectrograph, the calibration of the conductivity probe and the initiation of low temperature experiments in Neon-Ar gas mixtures. In addition a study was initiated to determine the effect of the Lorentz body force on magnetically induced ionization.

5207
General Electric Co., Space Sciences Laboratory, Missile and Space Division, Philadelphia, Pa.

Solutions are given to MID Couette flow systems with increasing complexity. Finally the problem of Couette flow with an oscillating transverse magnetic field is solved. The solution is obtained by means of a transformation which demonstrates the similarity between a set of transient MHD systems and a set of transient heat conduction systems. Under various conditions, the solution of the oscillating MHD system reduces to various solutions of simpler systems. Although the Couette flow system was chosen for simplicity, the results of analysis are useful for the determination of: 1) The start-up time interval for both MHD-AC and MHD DC systems. 2) The steady state distortion in the alternating current output for MHD-AC systems.

5208

Authors briefly review problems associated with direct conversion of kinetic energy of an ionized gas into electrical power in a magnetogasdynamic (MID) generator. These include choking, ionized gas production, losses, and materials. The Hall effect and its suppression or utilization and non-equilibrium, low temperature, ionization are only noted in passing. Discussion following paper contains interesting description of microscopic behavior of gas during conversion. (Appl. Mech. Rev., 16:404, May 1963).

5209
Great Britain, Aeronautical research Council, London.

Adiabatic expansion through a converging-diverging nozzle causes a temperature drop with increase in gas velocity and as initial temperature is limited by combustion the temperature falls too low for appreciable ionization. Thus presenting a problem in the open, classical cycle MID system. Three methods for overcoming the difficulty are outlined: 1) use of a static layer system requiring two fluids, 2) a pulsating combustion system making use of the fact that combustion at constant volume gives a pressure rise which can be converted directly into velocity, and 3) a continuous shock tube system.

5210

Although still far from being a reality, the direct conversion of heat into electricity through interaction of the working fluid with a magnetic field no... because of recent developments, warrants serious attention.

5211

Discussion of methods of applying MID to smaller power plants, particularly to peak-load stations. An approach toward optimizing a combined MID and gas-turbine power plant and a method of generating alternating current are presented. An analytic method is proposed for establishing the values of total pressure level and other flow variables which result in maximum MID generator output per unit size. Several gas-turbine cycles are proposed to reduce cost of the MID power plants for peak-load operations. (Intern. Aerospace Abs., 3:A63-14036, May 1, 1963).

5212
Hepworth, M.A. and Arthur, G. CERAMIC MATERIALS FOR M.P.D. POWER GENERATION. Preprint Paper 39, Session I, Pre-
Publication Copy. 12p. (Thermal Syndicate Ltd., Wallsend, Eng.).

Various oxides were heated in Ta and W crucibles at temperatures up to 2,200°C, and the weight losses were measured. From these results and published data, it was concluded that W electrodes and HfO₂ or ThO₂ insulators could be used in a closed-cycle magnetoplasmadynamic generator. For an open-cycle generator, electrodes of "doped" ZrO₂ and insulators of SrO₂ZrO₂, HfO₂, or ThO₂ would be possible. (Nuclear Sci.Abs.,17:9073, Mar.31,1963).

5213

In French. Presents a review paper, which starts with the fundamental equations, and develops the concept of conductivity in a plasma. A number of different methods of utilizing a moving plasma in the generation of electricity, including the use of the Hall effect are considered, and the use of small additions of alkali metals to increase the conductivity is discussed. The specific power produced as a function of temperature is one of the main factors with which the designer is concerned. Using established techniques, a temperature of 2500 K is required in order to attain attractively high efficiencies, but this imposes requirements on the materials for the combustion chamber which can barely be met at the present time. However some improvements in ceramic materials are confidently anticipated, to lead to higher plasma conductivities at lower temperatures, eventually possibly as low as 1500 K. (Elec.Eng.Abs.,66:73, Jan.1963).

5214

This paper discusses the techniques, advantages, and future prospects of generating electrical power by magnetohydrodynamical means.

5215

Magnetohydrodynamic power generation has been presented as limited in application to large generating stations but offering the promise of reduced power cost to be achieved through heat rate improvement. The potential for industrial application will be broadened if generators can be made attractive in smaller ratings, if generating cost can be reduced, and if the generator can be made lighter and more compact. The scaling considerations which make large output more favorable will be reviewed and the possibility of devising attractive MHD generators in smaller ratings will be explored.

5216

Chapter IX reports research on plasma magnetohydrodynamics and energy conversion.

5217

Chapter 8 considers research on plasma magnetohydrodynamics and energy conversion.

5218

The problems associated with the use of electrolytes in scale models for tests of MHD Generators are discussed. It is concluded that the Hartmann number and fluid Reynolds number must be matched between the model and the full scale device. (TAB 163-1-5:22, Mar.1,1963).

5219

Brief outline of a research program the objective of which is the designing and constructing of MGD devices for direct conversion of heat into electricity. The P.1 plasmatron, initially developed from this program, and its improved version, the P.3, are described, as are the MGD generators, G.1 and G.2, designed to supplement these plasmatrons. Photographs and design diagrams of these devices are presented. Experimental research aimed at the analysis of generator operation is noted, as well as the investigation of the conductance...
of thermally ionized gases, the flow of a conducting fluid in a magnetic field, and the various phenomena associated with the use of electrodes. (Intern. Aerospace Abs., 3: A63-13916, May 1, 1963).

5220

In French. Two types of thermoelectric converters in which the space charge is compensated for by a natural plasma of cesium ions were developed. The heating of the cathode is obtained in the first model by electron bombardment and, in the second, by a luminous radiation falling on the cathode. A maximum yield of 14% with 115 amp under 0.72 v was obtained. (Nuclear Sci. Abs., 17:16186, May 31, 1963).

5221

A study of crossed-field microwave devices for the generation of very large amounts of microwave power in conjunction with the use of a magnetohydrodynamic generator as a source of primary power has been important in establishing better understanding of the power potentialities of the Electromagnetic Amplifying Lens.

5222
Virginia University, Department of Aerospace Engineering, School of Engineering and Applied Science, Charlottesville, Va. MAGNETOHYDRODYNAMIC POWER GENERATION - ITS PRINCIPLES AND PROBLEMS, by W. C. Moffatt. 24p., Jan. 1963. (Project Squid, TR) (MIT-29-P) (Contract Nonr-3623(00)).

The increasing reliance on thermal plants for the production of electrical power has prompted a growing interest in unconventional power generation techniques. One of the most promising of these, and one which is the focus of a considerable research and development effort, is magnetohydrodynamics. This scheme envisions the generation of power by passing an electrically conducting fluid, usually a high temperature gas, through transverse electric and magnetic fields. In its simplest form, this type of machine is exactly analogous to the conventional generator except that a moving fluid conductor is substituted for a rotating wire-wound armature. In this paper the basic operating principles of an MID generator are presented, and some of the major problems yet to be overcome before such devices become practical realities are described. Typical power plant arrangements incorporating MID channels are set forth, and estimates of the relative costs of plants and power production for a number of configurations are presented.

B. Principles

5223

In Polish. A study is made of thermodynamic and gasdynamic phenomena occurring in so-called magnetohydrodynamic generators. The derived formulas are based upon simplifying assumptions relating to the working medium. Changes of state are presented in heat diagrams (T-S) and work diagrams (P-V). (Nuclear Sci. Abs., 17:634, Jan. 15, 1963).

5224

A graphical process is outlined, which presents a clear survey of certain properties exhibited by various types of magnetohydrodynamic (MID) generators. For this purpose a diagram is devised which contains the curves for constant electrical and brake outputs and for constant efficiency. Every generator corresponds to a well-defined section of the diagram. As an example, the output characteristics of various types of generators are investigated.

5225

A certain quantity of gas is enclosed between two co-axial glass tubes (diameters 67 and 87 mm). In this annular space thus formed exists a permanent magnetic configuration, whose lines of force are perpendicular to the surface of the tubes (0-500 gauss). An electric field is then produced by induction such that its lines of force are circles whose axis coincides with that of the tubes (200 V/cm). The electric field lasts for 0.5 sec. This field ionizes the gas and causes an electric
current to flow perpendicularly to the magnetic field. The corresponding Laplacian force accelerates the plasma along the axis of the tubes.

5226

In Polish. D.C. energy is produced in an electrically conducting gas passing through a magnetic field which is normal to the gas flow. The electrical energy produced is equal to the total enthalpy drop in the gas. Only the working chamber is discussed. The basic equations are derived and then three special cases are described: (i) constant velocity; (ii) constant cross-section; and (iii) constant pressure. Some conclusions are presented in the form of graphs. (Elec. Eng.Abs., 66:4205, Apr.1963).

5227

Steady flow of a conducting gas in crossed, longitudinal electric and transverse magnetic fields is treated. The conductivity is taken as the scalar conductivity multiplied by a Hall-effect tensor. Owing to the complexity of the two-dimensional problem, a one-dimensional treatment is considered worth developing. In this, the invariance along the channel of mass flow and longitudinal current are taken into account.

5228

The principle of the procedure (expansion in a magnetic field of a high-temperature gas made sufficiently conducting by a convenient apparatus) is described. The admissible temperature limits are defined. The conductivity of the gas is determined, and expressions for the yield and power density are derived. The optimum shape for an acceptable yield is investigated. (Nuclear Sci.Abs.,17:5527, Feb.28,1963).

The electric impedance of an a-c generator is calculated for infinite-length generators and semi-infinite generators using a small perturbation expansion. The power factor and the power extracted from the generator are then determined. It is concluded that the plasma conductivity must be large if a-c magnetohydrodynamic power generation is to be economically feasible. For low-frequency operation, fringing losses must be kept to a minimum. High magnetic fields are necessary to obtain reasonable power densities at low plasma velocities. (Nuclear Sci.Abs.,17: 9077, Mar.31,1963).

5230

Results of two groups of experiments performed in cold cathode cesium diodes are given. The first group of experiments covered cesium-helium discharge phenomena in a diode configuration and were made to verify theoretical non-equilibrium concepts and formulations. The second group of experiments covered pure cesium discharges in a similar geometry and were conducted to answer questions concerning plasma conductivity, uniformity of discharge, and gradients produced in the positive column and the effect of wall conduction on the discharge. (TAB U63-1-2: 113, Jan.15,1963).

5231
General Electric Co., Space Sciences Laboratory, Valley Forge, Pa.

Magnetohydrodynamic power generation has now been under active development for over four years, but there has not yet appeared any complete description of the theory. This report is intended to close this gap. Most of the theory presented was developed by the author and personnel at the General Electric Company. The topics covered are: electrical conductivity in MID generators, optimum "speed" ratio, local analysis of the continuous and segmented electrode geometries; Hall geometry, helical flow geometry; magnetically induced ionization; polytropic efficiencies; compressible analyses of the constant velocity, temperature, Mach number, pressure and cross-sectional area flows; end losses;
AC generation; cycle efficiencies; and a summary of generating experiments at the General Electric Company and other places. Geometries other than linear are not considered herein; the most important of those omitted is the vortex generator.

5232

General Electric Co., Space Sciences Laboratory, Valley Forge, Pa.

THERMODYNAMIC CONSIDERATIONS FOR MID SPACE POWER SYSTEMS, by S.I. Freedman, 90p., Sept.1962. (Tech. Information Series R62SD83) (Contract Nonr 3867(00)).

Thermodynamic efficiencies and radiator sizes of Brayton Cycle MID generator systems with and without regenerators, were obtained. A new gas cycle, the Tri-Cycle, was synthesized. The Tri-Cycle has a radiator size as small as the regenerative Brayton Cycle, but a higher pressure ratio. A new cycle was discovered which operates on a dissociating chemical reaction and combines the advantages of a dry gas expansion, a liquid compression, and a Rankine Cycle size radiator. Entropy generation in supersonic MID generators was analyzed, the polytropic efficiency was related to the generator operating parameters. Transient boil-off and active refrigeration techniques were examined. Multiple radiation shield insulation thicknesses were computed. An optimum temperature ratio for heat rejection from an active refrigeration system was found.

5233


Equations have been cited which describe the flow of conducting gas in a magnetohydrodynamic generator (MIDG) with a rotating field. In this paper these equations are generalized a) by taking into account the dependence of the gas conductivity on the temperature and density, b) by not averaging with respect to the transverse coordinate and time, and c) by taking into account the voltage drop across the stator winding and the winding properties. A system of equations is derived for a specific asynchronous MIDG scheme. The concept of vector diagrams for a MIDG is introduced. The process of directly converting a portion of the kinetic energy of a gas into electrical energy and the delivery of that energy to a power net is illustrated using local and over-all vector diagrams. (Phys.Express 2:30-37, 1962).

5234

Japan Atomic Energy Research Inst., Tokyo.


In Japanese. A method of increasing the ionization in MID power generators by applying momentary electric fields to rare gases at 1000 to 2000°K seeded with low-ionization-potential gases was investigated theoretically. It was found to be theoretically possible to design and construct such generators using the non-equilibrium ionization state that is created by the initial stage of the electric discharge in the short interval between initiation of electric field application to the seeded rare gases and ionization saturation. (Nuclear Sci.Abs., 17:8922, Mar.31,1963).

5235


This note describes a simple flow in which the Hall current can be calculated exactly and the results compared with those that follow from the usual simplifying assumptions of reducing in fixed ratios the conductivities parallel and perpendicular to the field lines.

5236


Contribution of this paper to the expanding literature on the direct conversion of kinetic energy of a flowing gas into electrical energy is a closed form solution of the linearized set of one-dimensional steady flow equations and Ohm's law. Basis for this solution is assumption that results obtained using a one-step numerical integration from inlet to exit closely approximate results obtained using many steps on a digital computer. However, a detailed comparison is not presented to fully justify this assumption. Solution in terms of non-dimensionalized velocity and static pressure is used to derive an expression for conversion effectiveness, defined as the ratio of electrical power output to inlet stagnation enthalpy. This is plotted against load parameter, interaction parameter, and inlet Mach number for a monatomic working fluid. These curves peak at load parameters near one-half. While conversion effectiveness appears to increase indefinitely with interaction parameter for subsonic flow,
a finite limit is approached for supersonic flow. While the subsonic result appears to contradict the basic definition, the authors show that choking limits the possible values of interaction parameter to those yielding effectiveness in the vicinity of twenty percent. (Appl. Mech. Rev., 16:404, May 1963).

5237
MID Research, Inc., Newport Beach, Calif.
RESEARCH ON THE PHYSICS OF CONTINUOUS AND PULSED MHD GENERATORS, by M.S. Jones and others. 84p., Feb.1963. (Rept. 632) (Contract Nonr-3859(00)).

Short duration electrical pulses of 1.8 MW peak power have been produced from 10 grams of seeded condensed explosives by MID principles. The pulse length is about 10 microseconds. Low ionization potential materials are applied either as surface seeding or mixed into the bulk explosive. The effect upon power output of the geometry of the explosion tube, the size, geometry and composition of the explosive charge, and magnetic field intensity and electrode geometry are discussed.

5238

In Russian. Describes the basic principles of magnetohydrodynamic (MHD) generation, in which ionized gas at high temperature and speed is passed through a nozzle containing electrodes sited in a magnetic field. Gives equations relating the parameters of such systems and describes American investigations into MHD generation. The investigations are considered to be promising and it is hoped that conversion efficiency up to 55% may be obtained, but considerable work still remains to be done. (Elec.Eng.Abs., 66:2099, Feb.1963).

5239

The paper investigates the problem of finding the flow mode in the channel of a magnetohydrodynamic generator; this optimal mode assures the maximum removal of power per unit length of the channel or per unit of the channel. It is demonstrated that for any dependence of the gas conductivity on temperature and pressure and for a specified internal efficiency of the magnetohydrodynamic generator it is possible to find the optimal stream velocity and optimal dependence of the local electrical efficiency on temperature which assure the minimal length or minimal volume of the channel. (Power Express, 2:12-15, 1963).

5240

A formula relating complex quantities of the electric and magnetic field strengths, the current density and the gas velocity, is introduced, which can be used for determination of power output and losses. (Elec.Eng.Abs., 66:4145, Apr.1963).

5241


Equations which describe the flow of a conducting gas in a magnetohydrodynamic generator with a rotating field are generalized by taking into account the dependence of the conductivity of the gas on the temperature and density, by not averaging with respect to the transverse coordinate and time, and also by taking into account the voltage drop across the stator winding and the characteristics of the winding. A system of equations for an actual scheme of an asynchronous MHDG is obtained. The concept of vector diagrams of an a-c MHDG is introduced. The process of the direct conversion of a part of the kinetic energy of the gas to electrical energy and its entry into the network is illustrated with the aid of local and over-all vector diagrams.

C. Plasma Properties

5242

The widths of some of the spectral lines emitted from a dense plasma are sensitive to the ion density but insensitive to the electron temperature. In partially-ionized cesium plasmas with number densities greater than 10^13 ions-cm^-3 these plasma-broadened lines are easily measured and can be used as a simple diagnostic method for the determination of ion density,
5243

The elevation of the electron temperature is given as a function of a parameter, \( a \), which depends on the nature of the gas, the total temperature and gas pressure, and the strength of the magnetic field. An expression for electric conductivity is also derived. Graphs of the elevation of electron temperature as a function of \( a \) and electric conductivity, with and without elevated electron temperatures, as a function of \( a \) are presented. Electron temperature and electric conductivity in constant-velocity magnetohydrodynamic generators are studied, and the results are shown in graphs. It is concluded that much higher conductivities, electric currents, and power densities can be achieved if the upstream value of \( a \) is sufficiently large. Since \( a \) is proportional to the square of the magnetic field, the use of high magnetic fields in \( \text{M} \& \text{D} \) generators is indicated. It was found that the downstream value of the electron temperature may be higher than at the entrance of the generator under certain conditions, and the electric conductivity shows an increase along the length. (Nuclear Sci. Abs., 17:9009, Mar.31, 1963).

5244

Determination of the electrical conductivity of propane-oxygen flame gases with \( \text{K}_2\text{CO}_3 \), \( \text{KOH} \), and \( \text{CsCl} \) as additives, flame temperatures at 1,800°-2,400°K, and pressure at 1 atm. The results of potassium measurements are applied to the calculation of \( \text{M} \& \text{D} \)-generator designs for central-station power-plant applications. Variations in several cycle parameters are explored, and the effect of varying pressure ratio across the \( \text{M} \& \text{D} \) duct is evaluated. The reduction in performance with lower inlet temperatures to the \( \text{M} \& \text{D} \) duct is appraised. (Intern. Aerospace Abs., 3:A63-14041, May 1, 1963).

5245

A weakly ionized plasma in a uniform magnetic field is considered. Application of a potential across the magnetic field results in a steady current flow, owing to the finite conductivity. It is shown that this steady state is unstable if the plasma density is non-uniform in the direction of the applied electric field and if the applied potential is large enough. It is necessary that the sign of the product of the electric field and the density gradient be positive.

5246
General Electric Co., Space Sciences Laboratory, Missile and Space Division, Philadelphia, Pa. RESEARCH IN MID POWER GENERATION, December 31,1962, by G.W. Sutton. 73p., 1963. (Semiannual Rept. 1) (Contract Nonr-3867(00)).

Preparation of the shock tube for testing nonequilibrium ionization in \( \text{MID} \) generators was completed. Tests were conducted using Argon and Xenon as the driven gas in the shock tube. The Argon tests were conducted at gas temperatures of 3000°K and no current flow as observed in the \( \text{MID} \) test section. The Xenon tests were conducted at 5000°K, where the shock heated gas has a conductivity of about 100 Mho/M. Current Measurements in the test channel were obtained which could be due to a nonequilibrium effect.

5247

The purpose of the contract is to demonstrate magnetically induced non-thermal ionization in gases and vapors which will be suitable for use in closed-cycle nuclear \( \text{MID} \) generators. Non-thermal ionization is necessary because the allowable temperatures for materials for heterogeneous nuclear reactors is below that at which sufficient ionization of the gas may be obtained.

5248
General Electric Co., Space Sciences Laboratory, Philadelphia, Pa. THEORETICAL PERFORMANCE FOR MID GENERATORS UTILIZING NON-EQUILIBRIUM IONIZATION IN PURE ALKALI METAL VAPOR SYSTEMS, by F.Ii.
Each member of the alkali metal series has been investigated to determine the best system for a closed cycle MHD generator utilizing magnetically induced non-equilibrium ionization. MHD generator performances have been calculated for one-dimensional steady state flows with constant Mach number in which the dimer concentration is neglected. The calculations are for a generator with segmented electrodes. Potassium appears to be the best choice among the alkali metal series for a 1 megawatt generator operating at total temperatures near 1000 K and total pressures around 20 psia. The calculations show that the performance of an MHD generator utilizing a nonequilibrium condition of the electrons is primarily dominated by the elastic electron-neutral collision cross section.

First mechanism is based on the coupling between the quasi-longitudinal space charge waves and the quasi-transverse electromagnetic waves. Here the coupling between the two classes of waves is due to the scalloping of the finite current carrying plasma which drifts along the magnetic field. The mechanism is restricted to frequencies which are slightly below the ion cyclotron frequency. The other mechanism involves the interaction among individual transverse hydromagnetic waves which are supported by an infinite plasma drifting along the ambient magnetic field through an ambient plasma. The two mechanisms might find an application to the heating of the thermonuclear plasma and (b) to plasma propulsion. The analysis might also enable an explanation to be given to some of the whistler-type low-frequency radio noise and the enhancement of the solar radio-frequency radiation due to solar outbursts.

A nonequilibrium plasma is defined as a gaseous mixture of electrons, ions, and neutrals, each having a different temperature. It is useful in magnetogasdynamic energy conversion, since the desired electrical conductivity can be obtained at a lower mean temperature than with an equilibrium plasma. The production of highly nonequilibrium plasmas using the r-f electric field of an electrodeless discharge is described, and a theoretical analysis is presented. It was found to be difficult to use r-f excited plasma for MHD energy conversion because of the low density of the plasma, high diffusion and recombination losses, and reduction of effective conductivity by the Hall effect. Experiments to take advantage of the Hall and Klein effects are described, and graphs of the results are presented. The advantages of using r-f excited plasma for MHD energy conversion indicate that further research should be performed.

A linear macroscopic electrodynamic analysis of a fully ionized collisionless magnetized electron-ion drifting plasma interacting with an ambient plasma suggests two possible energy conversion mechanisms. The


Review of research on MHD power generation in the U.K. It is observed that this research is at an early stage, the experimental effort being mainly devoted to the demonstration of effects and to the development of measurement techniques suitable for future work. The exception is the investigation by Pain and Smy at Imperial College. More ambitious experiments are being planned or constructed, and there is interest both in the open-cycle system using combustion gases and in the closed-cycle system using inert gases. Emphasis is placed upon gaining an understanding of ionization phenomena and the physical processes which occur in the extraction of electric power from a plasma rather than upon the engineering problems of a prototype generator. (Intern. Aerospace Abs., 3:463-14032, May 1,1963).


The objectives of this program are to experimentally demonstrate the principle of non-equilibrium ionization under actual closed-cycle magnetoplasmadynamic generator operation conditions, to verify the basic phenomena underlying the behavior of moving ionized gases in the non-equilibrium state when interacting with a magnetic field by correlation of the experimental results with the theory of non-equilibrium ionization and to investigate the potential performance of the MHD power generator with non-equilibrium ionization in closed-cycle systems having a reactor heat source.


In the first part of the program, an experimental, closed cycle, electrically heated MHD electrical power generator has been designed and is currently under fabrication. In the second part a theoretical program contributed to the understanding of the basic factors necessary for the success of non-equilibrium ionization in the MHD generator using seeded noble gases. Supporting the theoretical investigation is the third part which is an experimental measurement program on gas-filled discharge tubes containing seeded noble gases.


Experimental evidence of non-equilibrium ionization effects in the flow of unseeded argon gas through a magnetic field (diffusor) has been obtained. The voltage-current characteristics of the induced discharge using a heated tantalum cathode were determined for low total currents (less than 10-3 amperes). The V-I characteristic curve appears to follow that of the normal and abnormal glow discharges.


Three experimental programs and some of their results are described. The conductivity of potassium-seeded, propane-oxygen flame gases was determined by simple resistance measurements, using concentric graphite electrodes in a small furnace. Experiments were carried out with 2- by 4-inch MHD channels, using K-seeded Hz-air combustion gases at ~730 m/sec and 2100°K static temperature; the operating characteristics for both Faraday and Hall generators were measured in B-fields of 3 to 12 kgauss. Values of electron mobility were obtained in three ways and compared: from the variation of internal resistance with B for both types of generator, from the ratio of their open-circuit voltages, and from ordinary resistance measurements on the gas. Some materials problems in the operation of these generators are briefly
discussed. An experimental survey was made of the electrical conductivity of flame gases resulting from seeding with various other materials; in all, 26 elements were tried, 10 of which are known to have been studied elsewhere. (Nuclear Sci. Abs., 17:9099, Mar. 31, 1963).

5250
Nagamatsu, H.T., Sheer, R.E., Jr., and Weil, J.A.

The interaction of high-velocity air plasma with a transverse magnetic field is investigated in a supersonic shock tube. Shock Mach numbers vary from 15 to 31 and the corresponding equilibrium temperature range is 5500 to 10,000°K. At high Mach numbers the induced electromotive force across the probes, for open circuit conditions, agrees with theoretical prediction. For the plasma produced by a Mach-30 shock wave, the voltage across the electrodes with different external loads decreases nonlinearly with increasing current flow. The plasma resistance across the electrodes decreases drastically at high current flows.

With two copper electrodes at room temperature, area of 3.94 cm², it is possible to extract 447 amp from the plasma. The electrical conductivity increases with the current flow, and this is found to be greater than the theoretical value. For an average magnetic field strength of 6500 gauss, a power of 155 kw is extracted from the moving air plasma. Because of the nonlinear increase in the conductivity, the extractable power from the plasma is much greater than the theoretical prediction. (Nuclear Sci. Abs., 17:7491, Mar. 15, 1963).

5260
Princeton University, Plasma Physics Laboratory, Princeton, N.J.

Research at the Plasma Physics Laboratory continues to be directed partly towards achieving hot confined plasmas, and partly towards enhancing basic knowledge in plasma physics.

5261
Rosa, R.J.

In this paper a brief review is given of the basic principles of MHD power generation and its current status. The remainder of the paper will discuss the problem of obtaining the level of gas ionization required for MHD generation.

5262
Southern California University, Engineering Center, Los Angeles, Calif.

Theoretical and experimental work in four major areas are presented: (1) electromagnetic wave propagation in ionized media; (2) plasma diagnostics; (3) electromagnetic scattering properties of a plasma; and (4) amplification of plasma waves. The results of these investigations were discussed in publications and technical reports and are reviewed briefly.

D. Devices

5263
Abramov, B.


Russian scientists have recently designed and built the first low-capacity installation of the machineless magnetohydrodynamic type. Heat energy is transformed directly into electric energy and a great saving in fuel is achieved.

5264
Aerospace Corp., Los Angeles, Calif.

Progress in the materials studies of interest in the design and study of a magnetohydrodynamic (MHD) vortex generator for use in a closed cycle power conversion system is described. Experimental results of tests to determine the tensile strength properties of tantalum to its melting point are presented. Measurements of temperature creep and stress deformation definitely indicate that creep rate will rule out use of tantalum as the sole structural material at design stresses greater than 600 psi. Fabrication difficulties in the use of tungsten possibly may be overcome or alleviated by wire-wrapped construction. Design of an electron bombardment heated test facility to determine the electrical...
resistivity of high-temperature (2500 K) insulating materials is covered in detail. (TAB U63-1-5:20, Mar.1,1963).

5265
A vortex-type magnetohydrodynamic generator was designed and fabricated on the basis of currently available materials, and was tested to determine the feasibility of obtaining electric power from a seeded combustion gas. The combustion was oxygen-hydrogen, seeded with potassium hydroxide solution. A power output of 0.15 watts was obtained from a vortex channel which was 4 inches wide with a magnetic field strength of 4000 gauss. The gas flow rate varied from 0.4 to 0.7 pounds per minute. This result compares with a theoretical output of 29 to 60 watts which was calculated by digital-computer methods. The low output was due to material failures throughout the unit and particularly of the combustion chamber and the center electrode. The study program indicated that the small vortex MID generator has a significant potential provided that the experimental problems can be solved. (STAR, 1:N63-16303, Jul.8,1963).

5266
Component designs for a 300 Mwe magnetohydrodynamic (MID) power plant are prepared and assembled into an overall plant complex. The plant is coal burning with air for combustion and the MID generator operates in the peak temperature range. The MID generator produces 80% of the gross electric output and a coupled conventional steam boiler generates the remaining 20% from steam power. Brief descriptions are given of the MID generator, integrated MID and steam generating plant cycle, combustion and air preheat system, d-c to a-c conversion system, operating cycle temperature-entropy diagram, heat rates and efficiencies, and the overall plant layout. Theoretical energy production costs show a substantial improvement over conventional steam plants. Future MID applications and the major developmental problems to be solved are discussed. (Nuclear Sci.Abs., 17:5629, Feb.28,1963).

5267
Avco Everett Research Laboratory, Everett, Mass.

5268
An MID generator with segmented electrodes is idealized as a one-dimensional channel with infinite segmenting. Transient and steady state effects due to local non-uniformities on the remainder of the channel are investigated.

5269
Barnes, J.F. SOME CONSIDERATIONS INFLUENCING THE USE OF AN OPEN CYCLE MID DEVICE FOR THE GENERATION OF BASE LOAD ELECTRIC POWER. Preprint Paper 6, Session I. Prepublication Copy, 8p. (National Gas Turbine Establishment, Pyestock, Farnborough, Eng.).

5270
A magnetohydrodynamic "series generator" or "constant field direction generator" is described in which power is extracted through segmented series-connected electrodes to a single load. The characteristics of this type of MID generator are analyzed and compared to those of a similar generator in which the power is extracted through segmented electrodes into separate loads. It is concluded that the "series generator" delivers the same power density under load with less complexity than the generator with separate loads and is better suited for working at low values of the load factor. (Nuclear Sci.Abs.,17: 9085, Mar.31,1963).


Brief review of the basic theory of laminar, vortex power generators, and discussion of the general characteristics of the solutions. Some of the major assumptions on which the laminar theory is based are indicated. Those assumptions which are largely hydrodynamic in character, and hence can be checked experimentally in simulated vortex chambers driven by compressed air, are discussed in the light of such experimental work. The inevitable conclusion is that the flow in practical vortex power generators will be turbulent in nature, and that these turbulent profiles will differ markedly from those obtained with the laminar theory using a constant effective eddy viscosity. The development of a theory for the velocity distribution in incompressible, turbulent conducting vortices is attempted. Although no actual velocity profiles computed by the method developed are as yet available, it appears that the new theory is capable of describing properly the velocity distributions in turbulent vortices. (Intern.Aerospace Abs., 3:643-14037, May 1,1963).


The design and construction of a closed-loop magnetohydrodynamic device, consisting of motor and generator sections connected to end plenum passages, are described.

Helium seeded with Cs will circulate in the loop, and power may be extracted from the generator section while the gas is circulating. A theoretical analysis of the loop operation is presented. When completed, the device will be used to study MID duct processes, plasma characteristics and properties, and materials and structures for MID systems. (Nuclear Sci.Abs.,17:9091, Mar.31,1963).


A power output of 1,350 kw has been achieved by an experimental magnetohydrodynamic generator at the Avco-Everett Research Laboratory.


The problems involved in the design of power stations using a magnetohydrodynamic generator are discussed in detail. A thermodynamic analysis is performed on one scheme for a MID generator topping a steam cycle, and data are presented. Depending upon the gas pressure of the cycle and duct gas entropy, the cycle efficiency, for the system studied, was found to be between 48% and 58%, where the steam cycle without the MID generator would have an efficiency of 40.4% using the same assumptions. The performance of an MID generator is studied using the equations for flow of gas in a duct. The effects of gas conductivity and ion slip are discussed, and the heat-transfer loss is calculated. Magnet design and materials for the duct and electrodes are also discussed, and the major areas for further study are listed. (Nuclear Sci. Abs.,17:9085, Mar.31,1963).


Proposal of an MID power-conversion method which uses a channeled, electrically conducting fluid, an electromagnetic pump, and an MID generator. These are to replace, respectively, the mechanical coupling, drive motor, and generator of
a conventional rotating machine converter set. Consideration is restricted to the case of voltage transformation in dc systems, and to MID converters in which a liquid metal serves as the working fluid. It is concluded that the velocities attainable in a practical device using liquid metal (mercury) as the working fluid, together with presently available magnetic-flux densities, limit operating voltages to the range below 10 volts when the interelectrode distances are on the order of 1 m. Improvements in the fluid design and substitution of NaK as the working fluid would make the liquid-metal converter of practical interest in low-voltage, high-current systems. (Intern. Aerospace Abs., 3: A63-14040, May 1, 1963).

5276

The results of this study show that an MID power source is compatible with present day microwave generators, and that a system combining these two devices is technically and economically feasible and constitutes a very attractive package for super power microwave generation.

5277

The theoretical investigation encompassed both the electrodynamic and gasdynamic aspects of the a.c. MID generator and their relationship to each other. This report includes the following areas of investigation: generator impedance, side losses, fringing effects, channel flow, heat transfer, plasma viscosity, operating conditions, and starting transients. Parametric studies are included for several of these topics. The result of the above studies has led to the design of an experimental generator. Results indicate that the addition of a ferromagnetic material external to the generator improves the power factor characteristics. Power factors up to 0.4 are possible at low frequencies. Supersonic rather than subsonic operation of the generator yields the higher power densities. Fringing effects indicate the need for shading magnetic fields analogous to d.c. generators. Heat protection of the a.c. MID generator walls by transpiration cooling is feasible. (STAR, 1:N63-16115, July 8, 1963).

5278

The potential performance of a chemically fueled MID generator operating on an open cycle is considered. Chemical fuels other than fossil are considered. By appropriately selecting ultra-high-temperature fuels, extraordinarily high power densities can be achieved. A theoretical inviscid analysis is carried out of the channel flow for such a generator in order to determine its size, geometry, and weight. Calculations show that relatively modest magnetic fields are permissible so that appropriate configurations of permanent magnets are considered for this application. Some estimates are made of the weight of such a permanent magnet system. Consideration is also given to the heat transfer caused by the extraordinarily high gas temperatures. Tentative conclusions are that the heat loss in such generators can be handled by a combination of regenerative and radiative cooling. From theoretical calculations and estimates the fuel-plus-oxidizer flow rate for such an MID generator seems to be in the range of 3 kg/kwh, while the specific weights range from 6 to 3 kg/kw for the larger sizes. A number of potential applications for such an MID generator system are discussed. (Nuclear Sci. Abs., 17:9124, Mar. 31, 1963).

5279
Sternglass, E.J. and others. MID POWER GENERATION BY NON-THERMAL IONIZATION AND ITS APPLICATION TO NUCLEAR ENERGY CONVERSION. Nuclear En., 60-66, Mar. 1963.

One of the most severe limitations of MID power generation is the high temperatures required for thermal ionization. Two alternative, nonthermal ionization methods are considered: electron-beam injection and fission-product radiation. Electron-beam injection appears to be the most promising method. The thermodynamic cycle of a power plant incorporating a MID generator and a reactor is considered. The design of a MID generator with nonthermal ionization and the use of MID compressors are discussed. (Nuclear Sci. Abs., 17:16188, May 31, 1963).

5280
Sutton, G.W. END LOSSES IN MAGNETOHYDRO-
DYNAMIC CHANNELS WITH TENSOR ELECTRICAL
CONDUCTIVITY AND SEGMENTED ELECTRODES,

End losses of an inviscid magnetohydro-
dynamic channel having tensor conductivity
and segmented electrodes have been
4 calculated for a magnetohydrodynamic
power generator of this geometry. It was
found that the constant-current con-
figuration is more efficient than the
constant potential difference case. The
efficiencies increase with increasing Hall
effect, but constant magnitude extensions
to the magnetic field have very little
effect. The theoretical efficiency for
an aspect ratio of 10 and \( \omega/2 \) is only 74%.

5281
Swift-Hook, D.T. and Wright, J.K. THE
CONSTANT-MACH-NUMBER MID GENERATOR. J.

It is shown that the optimum design of
fuel in a magnetohydrodynamic generator
is close to the one in which the flow
Mach number remains constant. This
constant-Mach-number generator is analysed
in some detail and it is shown that the
optimum Mach number can be defined to
within a few percent. For a \( \gamma \) of 1.25, this
optimimum is near 0.85. For very short
ducts, the maximum power output is
obtained near matched-load conditions but
for rather longer ones maximum total
power output is obtained by working as
close to short-circuit conditions as is
practicable. Against this, the minimum
compressor requirements are found by
working as close to open-circuit conditions
as is practicable, and so a compromise
must be reached for optimum overall
generator design as far as load conditions
are concerned. This will probably give
an internal ohmic loss in the fluid of
about one-third of the total output.
Curves are presented which enable the
optimum Mach number to be determined
with greater precision when the optimum
load conditions have been selected.

5282
Swift-Hook, D.T. LARGE-SCALE MAGNETOHYDRO-
DYNAMIC POWER GENERATION. Brit.J.Phys.,

The basic physical principles of magneto-
hydodynamic generation are described
and the electro-dynamics and thermodynamics
discussed. The interaction is controlled
by the plasma conductivity, which is low,
and methods of increasing it are
mentioned. The quasi-one-dimensional flow
equations are presented and methods of
solution outlined. The practical problems
are discussed and a survey is made of
experimental work to date. The immediate
prospects for open cycle fossil fuel
devices give grounds for cautious
optimism and possible future developments
include superconducting electromagnets,
closed cycles for nuclear applications
and a.c. generation.

5283
Thompson Ramo Wooldridge, Inc., TAPCO
Division, Cleveland, Ohio.
RESEARCH AND DEVELOPMENT ON A VORTEX MID
POWER GENERATOR, September 21,1960 -
(Final Rept.) (Contract NAS5-703)
(ER-4737).

An experimental and theoretical program
was conducted in order to investigate
the performance of a continuous-flow
crossed-field MID (magnetohydrodynamic)
power generator within which the working
fluid has a vortex motion. The experi-
mental effort involved construction and
operational test of small vortex and
linear channel generators as well as
cold-gas vortex chambers. The primary
emphasis of the theoretical study was
concerned with improving the understanding
of turbulence in two-dimensional vortices
and in defining optimum methods of
attaining the desired velocity profiles.
During this effort a theory of turbulence
in a vortex, based on the concepts of
mixing length, was evolved. (Nuclear

5284
Thompson Ramo Wooldridge Inc., Cleveland, Ohio.
RESEARCH ON THE VORTEX MID POWER
GENERATOR, by W.C. Davis and R.T. Craig.
2lp., Oct,1962. (Q.Prog.Rept.2)
(Contract NAS3-2526).

Fabrication of the experimental model of
the vortex magnetohydrodynamic generator
was completed and appears to be satisfactory
in its conceptual design. A gas dilution
calorimeter was constructed for determining
the enthalpy of the driving jets under
conditions simulating those within the
generator. The calorimeter will also be
used for determining local heat transfer
coefficients within the vortex generator
and generator conversion efficiency. The
vortex chamber installation was completed
and soon will be providing more comprehen-
sive and accurate data for the deter-
mination of velocity fields within vortex
cavities supplied with and without center
bodies. Further study of the application
of pseudo-laminar boundary layer analysis
to the prediction of velocity profiles
within a turbulent vortex confirmed the
earlier expectations of its successful
employment. (Nuclear Sci.Abs.,17:2363,

5285
Thompson Ramo Wooldridge Inc., TAPCO Division,
Cleveland, Ohio.
RESEARCH ON THE VORTEX MHD POWER
Rept. 3) (Contract NAS3-2526).

Efforts toward providing instrumentation for the vortex MHD generator tests and
for the vortex chamber apparatus to be used in turbulent vortex flow studies are
reported. (Nuclear Sci.Abs.,17:13623,

5286
Way, S. COMPARISON OF THEORETICAL AND
EXPERIMENTAL RESULTS IN AN MHD GENERATOR.
Symposium on the Engineering Aspects of
Magneto-hydrodynamics, 2nd, Proceedings,
Aerospace Abs.,3:A63-14039,
May 1,1963).

Discussion of experiments involving the
determination of the importance and extent
of the effects of loss factors such as
leakage currents, thermal losses, and
electrode drops in the evaluation of the
MHD power-generation scheme. Comparisons
are made with theoretical findings. It is
concluded that (1) it is possible to
build MHD generators with open-circuit
voltages closely approaching the theoreti-
cal value, (2) theoretical conductivities
for combustion products tend to run about
25% higher than experimental values; (3)
actual power is appreciably lower than the
theoretical generated power for the
actual gas conductivity when leakage
currents are present; (4) thermal losses
ahead of the generator must be prevented
to assure good fuel economy in an actual
MHD plant; and (5) realization of the full
potential of MHD power generation requires
close attention to thermal insulation and
appropriate design measures to prevent
internal leakage currents. (Intern.

5287
Woodson, H.H. and Lewis, A.T. SOME REQUIRE-EMENTS FOR THE OPERATION OF MAGNETOHYDRO-
DYNAMIC INDUCTION GENERATORS. Symposium
on the Engineering Aspects of Magneto-
hydrodynamics 2nd, Proceedings, Philadelphia
Pa., Mar.9,10,1961. In Engineering
Aspects of Magnetohydrodynamics. New York,

Consideration of an MHD machine that is
analogous to a conventional reluctance
machine or induction generator. The
starting point is the assumption that
single-frequency ac power is to be
generated, which leads to an equivalent
circuit that is necessary to satisfy this
assumption. Analysis of the equivalent
circuit shows some general properties of
the system in terms of circuit para-
meters, which in turn are related to gas
properties by using experimental results
obtained with magnetically driven shock
tubes. This process yields an unambiguous
specification of the gas properties that
must be achieved to obtain certain perfor-
mance characteristics. It is indicated
that more exact data on gas behavior are
needed to make the analysis accurate
enough for engineering design. The
physical model considered consists of
a cylindrical, nonconducting channel
with a concentric coil. Slugs of con-
ducting material are assumed to traverse
the region of the coil periodically.

VI. ELECTROCHEMICAL PROCESSES
A. Fuel Cells
1. General Information

5288
Engelhard Industries, Inc., Newark, N.J.
HYDROGEN GENERATION FOR FUEL CELLS,
November 1, 1962 - January 31, 1963, by
E.J. Emerson, L. Kantrowitz and H.H.
(Q.Rept. 3) (Contract DAS6-039-sc-89077).

A research project is carried out to
develop a method of generating hydrogen
from primary fuels in such a manner that
the generation of hydrogen and its
separation from other reaction products
can be accomplished in the field on a
portable basis. Successful operations
continued on a portable hydrogen generator
utilizing ammonia feed at a pressure of
35 psig. The waste stack gas was utilized
successfully as the source of heat of
vaporization to the liquid ammonia to
maintain the ammonia vapor at the necessary
operating pressure. Suitable mixtures of
water and JP-4 have been emulsified by
simple shaking with an emulsifying agent.

5289
FUEL CELLS GENERATE INTENSE INTEREST. Chem.

A review of Advances in the technology of
fuel cells, plus a close scrutiny of their
future uses are presented from a recent
Army-sponsored conference on power
sources.

5290

Fuel cells will be needed in the next
decade as primary electric generators of
intermediate power, i.e., 100 W. and
10 kW., for spaceflights lasting from a few hours to several days or weeks. Principles of their operation, particularly in relation to the factors and processes which control power yield and heat loss, are discussed. At the present time the most reliable device available is basically a hydrogen/oxygen cell working at 100-200°C. with concentrated potassium hydroxide or an ion exchange resin as the electrolyte. The gases may be carried cryogenically or in chemical form, Brief reference is made to other types of fuel cell.

5291

In German. The first part of a review article discusses the electrochemistry of various types of fuel cell and indicates the kind of voltage-current characteristic that is obtainable. (Elec. Eng.Abs.,66:528, Jan.1963).

5292

In German. The fourth method, discussed here, is the use of the fuel cell, in which gaseous fuels are fed to an electrolyte where by electrochemical action they are transformed into the production of electrical power. The process is continuous while current is drawn and fuel supplied. There is no stored energy as in a battery. The thermodynamic theory of the cell is outlined and several proposed models described (those of Bacon, Union Carbide, Justi), operating for low temperature or high temperature. Constructional problems and some practical results are discussed. Life characteristics are briefly compared with those of solar cells and isotope cells. (Index Aero. 17:55, Oct.1961).

5293

This report on fuel cell research on the European continent deals with the main lines of present activities, i.e., high temperature cells with semi-solid electrolytes, the Bacon HYDROX cell operating at medium temperatures and high pressures and the electrochemical energy converters operating at ambient temperature and pressure. The author devotes the main part of his report to these low temperature types including the Double Skeleton Catalyst ("DSK") system of the German Fuel Cell Consortium, the Swiss Mono-skeleton ("MSK") system and the German system of dissolving a liquid carbonaceous fuel such as methanol in a cell with catalytically different electrodes. In addition, various applications of such cells, e.g., for storage of electrical energy by electrolysis of water and subsequent recombination of hydrogen and oxygen are reviewed.

5294

The efficiencies obtainable with a primary electric cell, utilizing the reaction of a gaseous or solid fuel with oxygen, are considered in relation to the change in entropy determined by the change in the number of gas molecules. Recent types of fuel cells are discussed, especially the H2-O2 cell with an aqueous electrolyte and the Davyan cell with a so-called solid electrolyte consisting essentially of a porous solid phase impregnated with molten salt. Performance data are given for these and more recently constructed cells subjected to duration tests. It is shown that the combination of a fuel cell and a water-gas generator as proposed by Forin offers no increase in electrical energy produced. (J.Appl.Chem.Abs., p.49, 1955).

5295

The current intensive effort on fuel cell research and development is justified by the potential uses and advantages. Many industrial laboratories are investigating some form of mobile power in which high efficiency, low manufacturing cost, and low maintenance are the most important factors. Another potential large application for fuel cells and the one that is receiving the most attention at this time is in aerospace vehicles where this form of power satisfies many special needs.

5296

Fuel cells have emerged from the research laboratories and are now in the state of being actively developed for various military and commercial purposes. The paper tries to describe the principal problems which had to be overcome to build reliably operating, relatively inexpensive
cells. The different systems presently used are compared with each other and the possibility of the use of cheap hydrocarbon fuels in low temperature cells is discussed.


A survey is made of three types of primary fuel cell systems now in battery engineering phases. The three cell types are: 1) those using aqueous electrolytes; 2) those using molten electrolytes; and 3) those with solid electrolytes. Ten aqueous-electrolyte cell systems, six molten-electrolyte cell systems, and three solid-electrolyte cell systems are reviewed. Seventy-eight references are cited.


In theory, fuel cells are 100 per cent efficient and so should be superior to batteries and conventional engines as soon as cheaper electrodes are developed. These adaptable devices are likely to be used in small power stations, motor vehicles and in spacecraft.


Investigates from an engineer's point of view, some of the expected applications of fuel cells in the main industrial areas, i.e., output of electric power and "direct" output of mechanical work. (Battelle Tech.Rev., 12:17a, Jan.1963).


An ion-exchange membrane fuel cell was chosen to furnish electrical power for the Gemini. The solid electrolyte fuel cell design, its developmental status, and key results to date are described briefly. Extensive testing experience has been favorable and substantiates the technical feasibility of the ion-exchange membrane fuel cell and its ability to perform its intended Gemini duty.


Abstracts (116, and some several pages in length) are given of sessions on primary and secondary batteries and their properties, fuel electrodes, oxygen electrodes, fuel cells, fused-salt corrosion and high-temperature fuel cells. The existence of these abstracts is no guarantee that longer corresponding communications will necessarily appear. (Fuel Abs. & Current Titles 3:1241, Feb.1962).


Studies are beginning on pulsed operation of fuel cells and space-biocell experiments.

2. Theory


By introducing an equivalent thermal potential fixed in terms of the heat of reduction, a thermodynamic equivalent circuit is determined for a fuel cell which yields the correct current-potential curve of the cell for low current by formal application of OHM's law. The thermodynamic power balance and the result of debethune for the thermodynamic efficiency also are given correctly. A linear electrical equivalent circuit is constructed which represents closely the electrical performance of the cell over a wide range of current (not approaching zero). The effect of polarization processes on the electrical power and efficiency is taken into
account through a single constant parameter. Introduction of the equivalent thermal potential into the circuit yields a thermodynamic equivalent circuit whose output computed by formal use of QH's law coincides exactly with that given by the electrical equivalent circuit. The correct electrical properties, thermodynamic power balance, and thermodynamic efficiency follow directly from the circuit. A general theorem is formulated, independently of the validity of an equivalent circuit, connecting the thermodynamic and electrical efficiencies of a fuel cell. Confirmatory experimental results based on hydrogen-oxygen cells are presented. The experimental results underline the large reduction in available power brought about by polarization processes in a fuel cell, in addition to that produced by the entropy change in the chemical reaction.


It is suggested that because of concentration polarization only strong acids or strong bases are suitable as electrolytes for commercially acceptable low-temperature fuel cells. If carbonaceous fuels are employed, acid electrolytes must be used, since alkaline electrolytes would react with the carbon dioxide produced. Experimental results are quoted to show that high performance oxygen and hydrogen electrodes can be made which operate satisfactorily in acid electrolytes.


Many fuel cell applications require the minimization of the weight, volume or cost of the fuel cell system. This paper provides the method for combining the characteristics of the application, the fuel supply and the fuel cell itself to determine the design point for the desired minimum. The procedure consists of formulating the total system size in terms of the cell operating voltage and determining the value of the cell voltage which makes the total a minimum. The procedure is entirely general for fuel cell systems regardless of their specific characteristics or of the fuel and oxidant combination used. It provides the theoretical derivation for the figure of merit for the total fuel cell system in a particular application.

3. Electrode Processes


The experimental program is designed to evaluate the potential applicability of various synthetic zeolites as hydrated solid electrolytes by investigating their physical and electrochemical properties.


This paper is a presentation of some of those aspects of electrode kinetics which pertain to fuel cells. It is intended as an introduction to the relevant theory of electrode kinetics. It does not give details of testing circuitry, nor does it review papers on electrode kinetics or fuel cell investigations. A brief mention is made of the application of the basic concepts to porous electrode structures.

5309 Florida University, Engineering and Industrial Experiment Station, Gainesville. A FEASIBILITY STUDY OF PALLADIUM AS A HYDROGEN DIFFUSION ELECTRODE MATERIAL FOR FUEL CELLS, by L.L. Chiu. 30p., illus., Oct.1,1962. (Summary Rept.5) (Contract DA 49-186-502-ORD-860) (AD-287 055).

Pd films as H diffusion electrodes in fuel cells were investigated and found to possess very interesting possibilities when the thickness is on the order of 100 Angstrom - or at temperatures above 200 C. Above 400 C, H transport through Pd films is found to follow a semi-logarithmic relationship, with an activation energy for diffusion of about 5.5 kcal/g-mole. At approximately 200 C, a low temperature phase having the approximate composition PdH1 forms with a heat of dissociation of about 8.5 kcal/g-mole. At temperatures below 150 C, the current density supportable by mass transport is too low to make Pd films suitable for gas diffusion electrodes in fuel cells. Additional experimental work is suggested to clarify the possibilities of using Pd as a fuel cell electrode under conditions other than those indicated above. (TAB U63-1-3:19, Feb.1,1963).
The purpose of this investigation was to identify and to study the step or steps that limit fuel-cell electrode performance. The electrodes considered were the typical porous, gaseous-diffusion type, and most of the effort was directed toward acquiring a more quantitative understanding of the effect of the different variables governing electrode performance.

Some aspects of electrode kinetics which would be of use to scientists and engineers working on fuel cells are presented. The report is intended as an introduction to the relevant theory of electrode kinetics and it does not give details of testing circuitry, nor does it review papers on electrode kinetics or fuel cell investigations. (TAB U62-4-5:34, Dec.1,1962).

Adsorption of oxygen on oxide free platinum electrode has been studied in pure 1 N H$_2$SO$_4$ solutions. Coverage of electrodes with oxygen has been evaluated for various partial pressures of oxygen and temperatures. Heat of adsorption was obtained at different coverages. Dependence of rest potentials on coverage and on the temperature was determined. Preliminary work on the study of oxygen electrode reactions is described.

Adsorption of oxygen on oxide free platinum electrode has been studied in pure 1 N H$_2$SO$_4$ solutions. Coverage of electrodes with oxygen has been evaluated for various partial pressures of oxygen and temperatures. Heat of adsorption was obtained at different coverages. Dependence of rest potentials on coverage and on the temperature was determined. Preliminary work on the study of oxygen electrode reactions is described.
range of physical properties was produced within each series. During the third quarter a series of electrodes possessing two and three zones of porosity were prepared. It was observed, for a given electrode material, that the reaction at the oxygen electrode is predominantly reduction to oxide when the coarse side of the electrode faces the electrolyte, when the fine side of the same electrode faces the electrolyte reduction to peroxide or perhydroxyl occurs. These observations were valid only for a given electrode material as no over-all correlation between electron change values and pore size could be made.

5317

This report covers the third phase of a program relating to the development of a thermally-regenerative lithium hydrogen fuel cell. Emphasis is placed on improvement of the solid columbium hydrogen diffusion electrode and methods for improving its performance. Various procedures are examined for purification of the operating media and for testing their purity. An all-columbium fuel cell is described, and the result of a successful test run embodying the data developed during the purification studies is presented. Data are included for the various test steps, and the information is analyzed and discussed.

4. Primary
   a. Hydrogen-Oxygen

5318

The design of a hydrogen-oxygen fuel cell system was undertaken. The fuel cell module design was finalized and space oriented components were fabricated for feasibility tests. Two laboratory models of a 50 watt orbital fuel cell package were assembled. The method selected to reject the heat burden produced by the fuel cell package operating in space is evaporative cooling using water. (TAB U62-4-5:33, Dec.1,1962 and TAB U65-1-4:28, Feb.15, 1963).

5319

A 1.5 kw experimental fuel cell system was designed and constructed. The hydrogen-oxygen fuel cell is an air cooled unit rated at 500 w at 12 v. It consists of 15 individual cells connected in series with each cell having an area of 0.489 sq. ft. (TAB U62-4-5:33, Dec.1,1962).

5320

Theoretical and experimental studies have been directed toward the development of the Vapor Pressure Control technique for the removal of by-product water from hydrogen-oxygen fuel cells.

5321

Measurement of the functional behavior of catalyst-impregnated ion-exchange membrane electrolytes in a modified H2-02 fuel cell was made. An improved imprinting technique (the hot press method) was developed for membranes. New membrane electrolytes were prepared, including films with a fluorinated matrix polymer and films containing cross-linking resins for enhanced mechanical strength. Significant improvements were also made on the water-retaining properties of membrane electrolytes. (TAB U62-4-6:179, Dec.15,1962).

5322

The O-electrode carriers were prepared from porous Ni skeletons filled with Cr-Ni active masses prepared by different methods; the most active was prepared from CrCl3 and Ni(NO3)2. With increase in the temperature at which the electrode carriers were oxidized, both the electrode
potential and the amount of electrochemical active O\textsubscript{2} adsorbed by the electrode, increased. The Cr-Ni active mass may be a good depolarizer for the O-electrode in a H-O cell, particularly at high temperature. (Chem.Abs.,58: 225-226, Jan.7,1963).


A description is presented of the status of electro-optical systems in the development of an electrically regenerative hydrogen-oxygen fuel cell for space application. The system performs the same function as a secondary battery in spacecraft, and shows potential advantages over batteries from standpoints of energy-to-weight ratio, cycle life, and operating temperature range. (STAR, 1:15, Jan.8,1963).


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While the objective of 4000 hours of operation at duty cycle power densities was not realized during this reporting period, cells of "Polymer A" Series A and Series D both exceeded 4000 hours at power densities higher than the average power density for duty cycle conditions. In addition, duty cycle operation for a period of approximately 1000 hours was achieved. During this reporting period a program was initiated to determine the causes of premature failures during duty cycle operation.


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Phase I of this program resulted in the development and test of a 35-cell 25-watt/28 volt space configuration fuel-cell module. The HOPE spacecraft, fuel supply tanks, pneumatics, and thermal systems have been designed and fabricated to provide operating capability in orbit for 7 days at 50 watts, compatible with the Blue Scout launch vehicle. A series of development tests were conducted to verify water removal, thermal design, and 30-day shelf-life of the fuel cell. The 35-cell module was subjected to a series of performance tests. During the last test, it performed continuously for 7 days at an average 27 watts/29.5 volts. Following this test, the module delivered rated power without interruption during vibration tests simulating Blue Scout booster environment. (TAB U63-1-6:11, Mar.15,1963 and Sci.& Tech.Aerospace Rept., 1:N63-15188, June 8,1963).


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The activities conducted on the HOPE (hydrogen-oxygen primary extraterrestrial fuel system) Phase I program are described. Included are: research on electrochemical reactions, hydrogen ion diffusion through polymeric membranes, internal mass transport of water through capillary action, and mass transport of water vapor through an ambient of diatomic oxygen gas at 1 atm. pressure. Project HOPE's ultimate objective was the design of a 500-watt fuel-cell power-system, including cryogenic fuel supply, for orbital applications. (Sci.& Tech. Aerospace Rept., 1:N63-15187, June 8,1963).

Experimental electrochemical techniques related to chronopotentiometric, galvano-static, potentiostatic and double-layer capacity measurements have been successfully applied to the ion-exchange membrane fuel cells. Different
114

types of reference electrodes have been developed. Physical and chemical properties of membranes have been investigated and related to fuel cell performance. Air-operated electrodes have been studied in single and multi-cell systems.

5329
General Electric Co., Direct Energy Conversion Operation, Lynn, Mass.,

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5330
Gregor, Harry P., Leonia, N.J.

Measurement of the functional behavior of catalyst-impregnated ion-exchange membrane electrolytes in a modified hydrogen-oxygen fuel cell was made. An improved imprinting technique (the hot press method) was developed for membranes prepared in the laboratory. Additional, new membrane electrolytes were prepared, including films with a fluorinated matrix polymer and films containing cross-linking resins for enhanced mechanical strength. Improvements were also made on the water-retaining properties of membrane electrolytes.

5331
Gregor, Harry P., Leonia, N.J.
ION-EXCHANGE MEMBRANE ELECTROLYTES,

The general objective of this investigation is the development of membrane electrolytes which permit higher power per unit of weight and volume, as well as long operational life in fuel cells.

5332

An attempt is made to show how hydrogen-oxygen fuel cells are integrated into a optimum powerplant for a space mission. Cell performance parameters are also discussed. The Hydrox cell, which employs hydrogen and oxygen reactants, dual porosity nickel-nickel oxide electrodes, and aqueous potassium hydroxide electrolyte, is considered. (Astron. Info.Abs., 7:70,503, Feb. 1963).

b. Carbonaceous

5333

Chief advantage of such a cell is that its fuel is cheaply obtained, easily stored and shipped. Other advantages fuel cells have over competitors: Efficient conversion of fuel to electricity. Reliability because of no moving parts. Noiseless operation. No electromagnetic signal.

5334
Engelhard Industries, Inc., Research and Development Division, Newark, N.J.

A research program is carried out on electrode catalysts for fuel cells employing liquid organic fuels. Complete oxidation of the fuel to carbon dioxide and water is required under expulsion of these products from the fuel cell. The electrolyte of the cell, therefore, must be of sufficient acidity to avoid retention of carbon dioxide.

5335
ESSO Research & Engineering Co., Products Research Division, Linden, N.J.

Research on the soluble carbonaceous fuel-air fuel cell has continued to concentrate on improving the performance of individual cell components and on translating these results into compatible electrode-electrolyte systems. These efforts encompass work carried out in three areas, namely the development of
the fuel electrode, the development of the air electrode, and their combination into a total cell.

5336

On April 23 the General Electric Company, of Schenectady, New York, presented the first public demonstration of a remarkable new type of fuel cell, which operates on a wide variety of common hydrocarbon fuels, including ordinary diesel oil. Fuel cells, convert chemical energy directly into electrical energy. They use common fuels and oxygen, but without combustion or moving parts. Because the fuel cell does not employ a heat cycle, the efficiency is inherently more than twice that of the best conventional power generators. Of all the several so-called "unique" energy conversion methods principally useful as portable power sources, the firm is presently most optimistic about fuel cells, and a large number of space, military and marine uses await their further development.

5337

Fuel cells that run on inexpensive and readily available hydrocarbons, are a potential source of energy. Laboratory models have been developed. They will probably be used first by the military as portable power sources in field applications.

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5339

When formaldehyde and formic acid were investigated as possible fuels, large current densities were obtained with polarizations comparable with those observed for methanol. Similar results were found in alkaline and acid electrolytes, although somewhat higher fuel conversion efficiencies were obtained in the latter. ( Battelle Tech. Rev., 12:17a, Jan. 1963).

5340

Experimental studies are conducted on components of a carbon electrode fuel cell system, with emphasis on problems of operation in a space environment. A 500 watt (net electrical output) fuel cell system has been operated for 25 days continuously on fully automatic control in the laboratory. The performance is analyzed and related to the design of future flyable power systems.

c. Miscellaneous Fuels

5341

Prototype fuel cells were operated employing chlorine as oxidant, phosphorus trichloride as fuel, and methyl thiocyanate as solvent. Studies were made of pyrolytic processes for regeneration of reaction products and means of separating products. Other systems were investigated by chronopotentiometric techniques. Tungsten and antimony chlorides were found to have characteristics of special interest. ( TAB 063-1-1:21, Jan. 1, 1963).

5342

Substantial progress has been made in the study and operation of potassium-mercury cells and in pointing up problem areas requiring solution. Six different types of cells were run, some utilizing a ceramic matrix while others operated on a differential density principle. Certain cells were operated with flowing cathode metal, so that steadiness of operation and regenerative capability could be studied. Results confirmed this regenerative capability up to 60 mw/sq. cm, the operating level of the experiment. Liquid metal cell
life was extended to as long as 550 hours to date. Current densities of 227 ma/sq. cm and power densities of 91 mw/sq. cm were achieved. Composite matrices composed of 6-micron MgO particles were produced, and electrical conductivities of discs of various electrolyte/MgO ratios were measured. Results conform to requirements of liquid metal cell systems. (TAB U63-2-4: 17, May 15, 1963).

5343


Progress has been made in the following areas: 1) small differential density cell (DDC)-resistivity cell studies; 2) conductivity measurements of coarse grain composites; 3) strength measurements of coarse grain composites; 4) development of a preparation technique for fine grain composites; and 5) design of a small LMC and test rig.

5344


A fuel-cell battery was built which generates 15 watts at 5 amperes for 8 hours, utilizing hydrazine (SM in 1.4 KQH) as fuel and nitric acid (10%) as oxidant. The battery consisted of 3 cells, each having an electrode area of 120 cm². The open-circuit voltage was 5.95 volts. Over the 8-hour period, the total current was just over 5 amperes at an operating voltage of about 4 volts. The battery produced 35 watt-hours/pound. Pentaborane and hydrogen peroxide were also tested as fuel and oxidant, respectively, with each other and with hydrazine and nitric acid.


5345


Data are presented that were obtained with Baur-Broers cells having a MgO matrix that carries molten LiNaCo3 electrolyte in its pores. II, reformed hydrocarbons, and anodic fuel and of cathodic oxidizer is provided; kinetic principles, concepts, and definitions; transport processes in fuel cell systems; efficiency and material balance; scale-up of fuel cells; design...

5349

The objective of the program is to develop and deliver three multi-cell regenerative hydrogen oxygen fuel cell assemblies to the Jet Propulsion Laboratory.

5350

A study of photochemical and thermochemical approaches to the conversion of solar energy to electrical energy is reported. A closed-cycle photo-regenerative system was operated for 90 days at conversion efficiencies approaching 0.21. Methods of thermal regeneration which were studied include thermal dissociation, electrolysis at elevated temperatures and electrolysis into low pressure regions. Thermal regeneration appeared completely inapplicable to the systems studied. Although the electrolysis methods were feasible in principle, their application awaits the solution of materials handling problems. Fused salt thermocells employing regeneration by mass transfer were also investigated. Elementary thermocell devices were constructed and tested.

5351

Chronopotentiometry has been utilized to measure the rate constants for the first electroreduction step at platinum in dimethylformamide solution of several chloride compounds of interest for regenerable fuel cell systems. The chronopotentiometric curves were also used to determine the diffusion coefficients and the products of the transfer coefficients with the number of electrons involved in the rate-determining steps. Tungsten hexachloride obeyed the chronopotentiometric equation of reversible reactions, with an E1/4 of -0.159v (vs. a gold reference electrode) for its one-electron first reduction step. The reduction of SbCl5 to SbCl3 was irreversible and occurred in two steps, suggesting the intermediate formation of SbCl4. The reductions of phosphorus chlorides and several group IV A chlorides were also found to be irreversible. Some correlation was noted between bond energies and the reciprocals of the rate constants. The electrode surface-area requirements for minimizing activation polarization for PCI5 and SbCl5 were calculated from the rate constants and chronopotentiometric data. Using Latimer's method, it was estimated that the NCl6 fuel cell could produce 40% higher open-circuit voltage than the PCI5 fuel cell.

5352

An essential feature of a redox fuel cell employing a cheap hydrocarbon fuel is that the fuel must reduce the metallic ion (produced from the cell) at a reasonable rate. A large number of tests on the titanyl-titanous system and the stannic-stannous system, at temperatures up to 200 C, indicate that formaldehyde and methanol will not reduce the higher valent ion to the lower at a feasible rate. Considerations of thermodynamic equilibrium, solubility and mass transport predict that regeneration by hydrocarbons will be even less feasible. (TAB U63-1-4:31, Feb.15,1963).

5353

The separators tested in project were designed to show variance in separation between ground operation (+1.0G) and zero gravity operation as simulated by KC135 aircraft flying zero gravity trajectory. These separators, when sufficiently developed, are to be used in conjunction with the regenerative fuel cell. Because of safety precautions aboard aircraft, simulated fluids were used instead of actual fuel cell fluids. Design procedure for zero G separators is outlined in conclusion of report.
b. Biochemical

5354

The action of Desulfovibrio bacteria has been observed in a prototype biochemical fuel cell. The catalytic action of this microorganism in a properly balanced system, i.e., containing proper electrolyte-nutrient and bio-fuel combination, shows promise of yielding a practical, low-power biochemical fuel cell generator. Best results to date have been obtained with fresh mushroom as the bio-fuel where power levels of 1540 µW per square inch have been achieved. Further experimentation planned in this laboratory will be directed at improving the power constancy at the higher current-voltage drainage rates.

5355

A Biochemical Fuel Cell system consisting of algae and fecal bacteria produced 0.3V at 1.4 to 2.0 ma/sq ft. The biological mechanism was studied by using a simplified system which contained only one organism, Feischmann's yeast. Electrical properties were evaluated by analyzing polarization curves. These curves show a power density of 0.66 w/sq ft and a current density of 2.2 amps/sq ft at 0.3 volts. Finally, the catalytic action of the platinum-black was investigated. Bioelectric Potential has been measured in rats by placing electrodes in different parts of the body. The electrical output has been evaluated as above and indicates a power output of 90 microwatts at a current of 300 microamperes. For this study the electrode geometric area was about 75 sq mm. A 500 kc sine wave oscillator was designed and constructed and has been operated from the energy obtained from Bioelectric Potential of a 200 gram rat with implanted electrodes. (TAB U63-2-4:44-45, May 15, 1963).

5356
Magna Corp., Anaheim, Calif.

Studies of the biochemical influence on electrochemical phenomena were initiated as part of a program leading towards the development of biochemical fuel cells. Five biochemical systems were selected for study. Cultural and physiological studies of the Clostridium butyricum and Escherichia coli were started. The effects of pH, temperature, substrate concentration and salt content on gas evolution by the Clostridium butyricum are reported.

5357
Melpar, Inc., Falls Church, Va.

In the first report the initial experimental results and the planned course of action on this program are described. In the second report experimental investigation of microorganisms capable of producing hydrogen for fuel cell use is described.

5358
Ohio State University Research Foundation, Columbus, Ohio.

A comprehensive literature review has been made on the subject of Bioelectricity. The review includes the following topics: 1) Survey of species which produce Bioelectricity, 2) Mechanism of production of Bioelectricity, 3) Electrochemistry of membrane phenomena, 4) Preparation and properties of synthetic ion-selective membranes, and 5) Production of electricity by ion diffusion. The electric discharge characteristics were determined for two species of knifefish and for the electric eel. A cell was designed and constructed for the study of the impedance of single living cells from the electric organs of Electrophorus Electricus.

5359

A description is given of a battery of 6 yeast cells with carbon electrodes connected in parallel which gave 1.25 ma.

5360
Scott, W.R., Rohrback, G.H. and del Duca, M.G.
BIOCHEMICAL FUEL CELL POTENTIALITIES FOR

An introduction of biochemical fuel cells is presented, including the special characteristics of these cells, useful types of catalysts, and mechanism of reactions. A number of bioelectrodes are discussed in detail with performance data. The general application of bioelectrochemical devices to space vehicle operation is considered, including disposal of solid, liquid, and gaseous human waste products. Present and future capabilities are discussed. The point is made that as a result of their low power density biochemical fuel cells do not appear promising as power supplies. (Nuclear Sci.Abs., 17: 5663, Mar.15,1963).

B. Primary Batteries


This article discusses the history, basic types, construction, characteristics, testing, recharging and selection of batteries.


Thirteen different materials were checked for their reaction towards silver oxide dissolved in potassium hydroxide solutions. Of these, the polyethylenes appear to have most promise as separator materials. Several attempts were made to trace the migration of silver in a silver-cadmium cell by the use of radioactive silver. A method of counting the radioactivity is being developed. The main difficulty encountered in this study is the take-up of radioactive silver by the electrodes. This has obscured the interpretation of the results obtained to date. (TAB U63-14:29, Feb. 15, 1963).


A study was made of three methods whereby radioactive silver can be used to determine quantitatively the concentration of small amounts of silver dissolved in potassium hydroxide solutions. Good results were obtained by precipitating the dissolved silver as silver iodide and collecting this on a filter paper of sufficiently small pore size. The precipitated silver iodide was then counted. (TAB U63-2-4: 17, May 15, 1963).


An investigation has been initiated for the purpose of developing an automatically activated zinc-silver oxide battery, with a chemical heating device. The technical efforts are being directed toward meeting the general requirements of the standard BA-485/U, that is, 1.5 second activation throughout the temperature range of -40 to 165°F while maintaining close voltage regulation. During the quarter, a study was undertaken to determine the theoretical heat requirements to promote rapid activation, particularly at the -40°F ambient temperature. Approaches to meeting the overall objectives were also evaluated. Preliminary heating devices (heat exchangers) were also designed on the basis of the theoretical requirements.


The chemical polarization of the cell C(O2)/NaO1l (40%)/Zn, the e.m.f. of which is i.41 V., was determined in relation to the current strength and rate of feeding H2O2 dropwise inside the porous C electrode. With increase in the H2O2 feed rate, the generated current increased up to a limiting value when the rate was 100 drops/min. The working voltage of the cell, at constant generated current, increased with increase in the H2O2 feed rate. When the H2O2 feed rate was 20 drops/min. and the generated current was kept constant at 0.2 amp., the cell operated continuously for 54 hours, when the Zn has still not completely dissolved, the voltage dropping stepwise. The first step corresponded to complete conversion of the NaO1l in the electrolyte into zincate, in a solution of which Zn has a different potential than in NaO1l solution; the second step corresponded to almost complete dissolution of the Zn electrode. H2O2 is a good depolarizer for the C(O2) electrode. (Chem.Abs., 58:225, Jan. 7, 1963).

A review is given of the facts about the MnO₂ deposits which proved to be reproducible: e.g. dE/dpH, solubility of Mn⁺⁺, potential of MnO₁.5 oxides, ion exchange on Mn⁴⁺ oxides and hydroxides, etc. From these facts it was deduced that during electrolytic reduction of MnO₂, Mn⁺⁺ forms. These ions can (a) go into solution, (b) redosorb on Mn⁴⁺ hydroxide, or (c) react chemically with MnO₂. The depolarization reactions are different for these 3 cases. The E₀ values of lower Mn oxides increase with time in contact with electrolyte because a disproportionation of these oxides to Mn⁴⁺ and Mn⁺⁺ is observed. The rapid decrease of the MnO₂ potential at the start of discharge is due to the formation of Mn⁺⁺ around the cathode. X-ray diagrams of different reaction products are given. (Chem.Abs.,58:5255, Mar.18,1963).


Previous efforts toward recharging dry cells were chiefly concerned with the electrical results obtained. In this work, the recharging of Leclanché dry cells was studied more from the standpoint of the effects occurring in the cell during both the discharge and charging operations. It was found that fixed potential charging in the range of 1.7-1.9v was most satisfactory. Constant current charging can result in damage to the cells and is to be avoided, especially for cells arranged in series. A suitable fixed-potential charging circuit was developed. Typical performance characteristics of dry cells during charge and discharge are presented for various stages of cycling. Some of the factors limiting cycle life are described. It is concluded that recharging can extend the useful life of dry cells under carefully selected conditions.


The compositions of the electrolyte in the bobbins of D size dry cells were estimated from chemical analysis and electrochemical data, e.g., pI and zinc electrode potential. It was confirmed that zinc chloride concentration in liquid phase of Ni₄Cl₂-ZnCl₂-H₂O system was about 10-20%, the content of Ni₄Cl₂ crystal was about 5 g. and the content of ZnCl₂-2Ni₄S₄ was below 3% of the total electrolyte. It is concluded that the electrolyte composition differed very much from sample to sample by types of discharge. (JSR Mech. & Elec.,8:214, Aug.1961).


Change of hardness on the outer layer of the bobbin of D size dry cells was measured with a penetration tester during continuous and intermittent (30 min/day) discharge through a 4 ohm load. In the continuous discharge the outer layer temporarily softens in the middle of the discharge process, while in the intermittent discharge it tends to gradually become hard. These variations in hardness are attributed to the chemical change of the electrolyte in the very thin outer layer of the bobbin. (JSR Mech. & Elec., 8:214, Aug.1961).


Two routine methods for measuring the internal resistance of dry cells, internal resistance drop method and a.c. compensation method, were studied and compared. Significance of the measured values was discussed with an improved model for internal network of dry cells. The values obtained by the former method varied with the discharge current, but remained unchanged after some duration of discharge. These values were generally nonohmic, but had practical meaning, whereas the values obtained by the latter method were ohmic, but had no practical meaning. The dynamic change in a dry cell due to discharge could be successfully explained by the analysis of the relative change of the 2 values during discharge. (Chem.Abs.,57:10910, Oct.29, 1962).


Investigates the relation between the value of depolarizing activity of manganese dioxide evaluated by alkalified hydrazine sulphate method and expressed
in terms of the rate of hydrazine consumption, and also the continuous discharge period of D size dry cells through a 4 ohm load or a load equivalent to 4 ohm. The evaluated values for natural manganese ores - samples of -150 and +200 mesh sizes and of ordinary particle size distribution for dry cell use - were found to be related to the discharge period down to a final test voltage of 0.9-0.75 V with a significance level of 5%. Particularly, in the continuous discharge through a load equivalent to 4 ohm, correlation was observed with a significance level of 1% overvoltages of 0.85-0.75 V. (JSR Mech. & Elec., 8:65, May 1961).


The first of two steps in the cathodic reaction in the Leclanche dry cell is electrochemical reduction of MnIV to MnII. The 2nd step is the chemical reaction of MnIII produced in the 1st step with unreacted MnIV to form an insoluble MnIII compound. Two chemical reactions can occur producing MnOOH and 2MnO2, manganite and hetaerolite, respectively. The latter reactions, termed recuperation reactions, are slow enough to limit dry cell operation under certain conditions. The more active depolarizers, such as electrolytic MnO2, show more rapid recuperation reaction than the natural MnO2 ore. The basic concepts of heterogeneous chemical kinetics were applied to this problem, and a simple mathematical equation was found which was applicable to all the data. (Chem. Abs., 57:9569, Oct.15,1962).


Testing of cells was performed under the revised Signal Corps Technical Requirement, SCL-6274A. Work continued on cell types 12R, 42R and 64OR. In addition, cell types 1R, 502R, 625R, 1438R and 1450R were started in the program. The relative dispersion of cell test groups was used to limit testing to areas where useful data for battery application would be obtained. (TAB U63-1-4:30, Feb.15,1963).

5374 Naval Ordnance Laboratory, Corona, Calif. FEASIBILITY STUDY OF RESERVE LIQUID AMMONIA BATTERIES FOR GUIDED MISSILE FUZING, by W.C. Spindler. 36p., illus., Nov. 1, 1962. (NAWEPs Rept. 7240) (AD-288 531).

A liquid NiM battery is being developed to estimate its feasibility for short-life, reserve, primary applications. (TAB U63-1-4:60, Feb.15,1963).


An equation has been derived describing a complete battery discharge for the case when the current density distribution is uniform. The battery potential during discharge is given as a function of time, current density, polarization, internal resistance, and other factors. This equation will be used as a base for deriving the more general case where the current density over the face of the electrodes is uneven. This equation has a number of practical applications. It can be used to describe battery charges and discharges, capacities, power evolution, and predict capacities on the basis of limited data. The equation can be applied to the charging of batteries by changing the signs of some of the terms in the equation.


A survey of all types and a guide to their selection for portable and mobile electric power are presented.


Recommendation is presented that covers dry primary cells and batteries with object of enumerating types corresponding to most current needs, defining their characteristics, ensuring their interchangeability and limiting their number; recommendation specifies terminology and designations, dimensions, terminal arrangements and marking, and tests to be applied to determine performance. (Eng. Index, p.40, Jly.1963).

Characteristic data are presented for magnesium/magnesium perchlorate reserve cells discharged at temperatures as low as -40°F. Cathode efficiency data as a function of temperature and current drain are also presented. Factors affecting the performance of dry cell batteries were investigated. Cathode efficiencies, storage characteristics, and electrode surface phenomena were evaluated. Data are also presented for a newly developed magnesium/mercuric-oxide meteorological battery, including discharge data for temperatures as low as -58°F.


A survey is presented of experimental and commercial carbon blacks as used with m-dinitrobenzene in magnesium cells. The specification evolved lists low density, large surface area, high electrical conductivity and a maximum volume of voids in the compressed carbon black. This demands a fluffy carbon black which, in the presence of electrolyte, retains a measure of structure adequate for massive material transfer and diffusion processes. No commercial carbon black was found ideally suited for this cathode system. One available pure acetylene carbon black can be adapted, however, by means of an intensive mechanical "opening" process, especially with simultaneous introduction of a small quantity of V₂O₅.


Com. corn starch and potato starch were cross-linked by epichlorohydrin in alkaline solution. The degree of swelling of the cross-linked starch granules was measured by centrifugal precipitation, and the resistivity to acid or ZnCl₂ was investigated. The inhibiting properties of native and modified starches against the corrosion of the Zn electrode in dry-cell electrolyte were investigated. The effects of various types of starches and organic impurities on the potential of MnO₂ electrodes were studied. Starch gel was used as the electrolyte holder in a Leclanche-type dry cell because of its inhibiting property against the corrosion of the Zn anode and its low electric resistance. (Chem. Abs., 57:10908-10909, Oct. 29, 1962).

Examination of present factory product E-95 "D" size alkaline-MnO₂ cell at low temperatures with goal of optimizing said cell for low temperature, heavy drain use. Discusses improvements in electrode formulations which improve -40°F. service through higher carbon phase cathodes and higher area zinc anodes. Relates problems of Lot-Lot service uniformity with modified cathode formulation.


Finalization of improved cathode formulation for "D" size Alkaline-MnO₂-Zinc cell for use at low temperatures. Analysis of energy losses at low temperatures. Definition of sources affecting uniformity of service levels at low temperature from lot to lot manufacture. Discusses results from use of various separator materials. Further investigation of anode contribution at low temperatures.


Two chemically prepared depolarizers were evaluated in BA-30, BA-270/U and BA-279/U batteries for ability to meet MIL-8-180 requirements. Following a preliminary mix formulation study, preproduction samples and pilot line quantities of the above types were prepared. Every effort was made to use present production equipment and techniques since experience gained would permit rapid conversion during time of...
emergency. Both materials were nearly equivalent in output, although difficulty was experienced in meeting some of the specifications. It may be possible to overcome these shortcomings by redesign of components. (TAB 063-1-5:21, Mar.1,1963).


Tests were conducted to demonstrate the feasibility and to evaluate the capabilities of silver-cadmium batteries for satellite applications. (TAB U62-4-5:309, Dec.1,1962).

A survey of data on presently available electrochemical cells is presented. It is intended to aid the reader in selecting an optimum energy source for any device that requires battery power. C. Storage Cells

In Italian. Reviews uses of plastics in the manufacture of lead, nickel-cadmium and silver/zinc batteries. Nine basic plastics are compared regarding their abilities to withstand strong acids and strong bases. PVC, Polyester and Polystyrene appear as most suitable. Resins are compared in mechanical and thermal respects which are tabulated for those favoured industrially. ABS made from Acrylonitrile-Butadiene-Styrene being particularly suitable. Fibres in conjunction with resins used for making plate-tubes are best represented by high density PE (polyester), specific weight 0.94-0.96 non-hygroscopic, minimum contraction on cooling. Proprietary applications of the above mentioned plastics have established themselves as successful alternatives to glass, ebonite, cellulose and steel in Pb, Ni-Cd and AgZn cells. Specific examples of successful developments in USA, Germany, England and Italy are cited. (Elec.Eng.Abs.,66:530, Jan.1963).

5387

Boeing Co., Seattle, Wash.


The storage battery for the Telstar satellite must undergo frequent charge-discharge cycles; in addition, it is subject to overcharge during a substantial portion of its life. Nickel-cadmium cells were chosen as best capable of satisfactory long-time operation under these conditions. A design and selection program was undertaken to ensure that Ni-Cd cores would meet objectives imposed by battery service conditions, and the cell enclosure was designed to minimize electrolyte leakage. Selection, qualification, and life tests indicated that a storage battery using the cell design would perform satisfactorily. To date, the only failures occurring during continuing life tests have been among cells subjected to 100% per cent discharge daily; this operation is far in excess of the expected duty cycle of satellite cells.

In French. By measuring the electro motive force of concentration batteries, the activity of Cd between 350 and 650 C in these systems is determined. The Van Laar model faithfully represents the progressive evolution of the deviation from the ideal condition of Cd-Sn-Au in proportion as Au is substituted for Sn. (Battelle Tech.Rev., 12:306a, Jly.-Aug.1963).

The alkaline battery applied research and failure analysis program is to establish a broad base of battery test data for use in the design of the electrical system of future vehicles and to determine the actual failure mechanism of all battery systems under varying environmental and cycle-life conditions so that improved space batteries can be developed. Another objective is to determine techniques and/or materials to prevent these failures, while at the same time increase the usable watt-hours-per-pound capability and cycle life of the battery.


The object of this study was to improve nickel-cadmium batteries through testing and analysis of failures. Vibration and acceleration tests were completed on samples of the Gulton VO-61S cells with no evidence of failures. Capacity measurements were completed on all the Gulton cells. Optimum capacity tests were completed on the Sonotone and the Gould-National cells. Data on the capacity measurements of the cells of each manufacturer and the optimum capacity of the Sonotone and Gould-National are presented. (STAR, 1:182, Feb.8,1963).


Experiment designs, test data, analyses and results for investigation of constant current charging at 75°F, 125°F, -10°F, and -40°F for fully discharged cells of Types B8412 and B8440 are presented. Since only one method has been investigated, no conclusions are drawn pertaining to charging methods, but analysis of the data shows that temperature, discharge rate, and cell type are the main factors controlling capacity obtained over the selected levels of the test variables.


Studies of various cell and electrolyte characteristics are recorded. Charge retention studies indicated that the major capacity losses found in previous studies were actually wattage losses rather than ampere-hour capacity losses, and were due to the lowering of the single electrode potentials during storage. Electrolyte decomposition potentials were measured for 31% potassium hydroxide under varying charge rates. The measurement of charge efficiencies and the effects of additives were initiated, but the data is inconclusive and further study is needed.


Results of investigations on plate parameters and electrolyte characteristics.
Development work has been directed toward the attainment of a reliable sealed cadmium - silver oxide battery. Among the areas investigated and discussed are improvements in separation, capacity efficiency, overcharge characteristics, and hermetic seals. In addition, the voltage, capacity, self-discharge, charge efficiency and life characteristics of cells utilizing the positive plate at both its divalent and monovalent oxide capacity levels are discussed. Although the ultimate in performance has not been attained, sufficient data have been accumulated to allow the construction of sealed cadmium - silver oxide cells with reliable performance characteristics.

A better understanding has been obtained of the factors contributing to the previously observed slower practical activation of the -53°C batteries as compared to single cells under ideal conditions. Tests indicate a larger percentage of the batteries activate in less than 3 seconds, with several about 1 second. A new high-rate cathode possibility (silver sulfate) has been found. Permion 300 separator has been found much better than cellophane for limiting the silver diffusion in the low-rate, long-duration application.
with nominal ratings of 20, 50, and 100 ampere-hours were constructed and tested. Contract objectives of 65 to 75 watt-hours per pound and 5 to 6 watt-hours per cubic inch have been met by the 20 ampere-hour cells and exceeded by the two larger sizes at discharge rates between 20 and 1000 hours in the temperature range 10°C to 50°C. Discharges at the 2000-hour rate are in progress with no serious degradation in performance expected.

General Motors Corp., Delco-Remy Division, Anderson, Ind.


Research and development program was conducted to provide an hermetically sealed silver oxide-zinc battery for use in satellite applications. Problem areas considered were: silver migration in cell, battery voltage regulation, zinc particle size and displacement during cycling, gas evolution, and terminal sealing. Sealed cells were designed, constructed, and tested electrically and environmentally.

General Motors Corp., Delco-Remy Division, Anderson, Ind.


Pd additions to the Ag positive plates of 0.2, 0.5, and 1% were tested in 25 amp/hr cells on the 2-hr cycle period. It was found that 1% Pd addition produces the maximum monovalent charge capacity of 50% and retains this level for approximately 200 cycles. Ag powders of different particle size were incorporated into 2 amp/hr cells and preliminary cycle data was obtained. Negative plates containing polyethylene oxide and polyvinyl alcohol are on the 2-hr cycle program. Five hundred cycles at 25% depth of discharge have been reached to date. Hydrogen evolution data was obtained from zinc negative plates containing 1, 2, and 4% HgO in various concentrations of KOH for a 2-wk period.

General Motors Corp., Delco-Remy Division, Anderson, Ind.


Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life.

Gould-National Batteries, Inc., Minneapolis, Minn.


The program involved 3 areas of study on the sealed nickel cadmium system: (1) separator materials; (2) cell closure and improvement in the performance of the glass-to-metal seal; and (3) a high vacuum method of testing cell seal.

Gulton Industries, Inc., Alkaline Battery Division, Metuchen, N.J.


A method for determining changes in a nickel-cadmium cell's electrical properties is discussed. The purpose of this work is to isolate those properties that vary with state of charge, the final goal being to develop a method for determining the residual capacity in nickel-cadmium batteries. The approach used is to determine the values of the elements in an equivalent circuit believed to be a good analog to a nickel-cadmium cell. These values are determined by balancing the equivalent circuit against a cell in a bridge. Designs for such a bridge are discussed. The operation of one bridge is described and equivalent circuit values for several cells are given. It appears even at this early stage, that at least one component, a resistor shunting the cell capacitance, increases with decreasing residual capacity in a cell.

Gulton Industries, Inc., Metuchen, N.J.


This report covers the second phase of a research and development program leading to improved, long life, sealed silver-cadmium batteries for aerospace applications. A silver electrode was utilized which yielded up to 50% of its capacity at the AgII oxide voltage plateau and the balance at the AgI oxide voltage plateau. Several separator systems were tested with regard to obtaining maximum cycle life.
The best separator combination consisted of single layers of Dynel-Polypor WA (coarse nylon base) - Fibrous sausage casing - V, each enclosing the positive electrodes in the order listed.

5409

Gulton Industries, Inc., Metuchen, N.J.


The work described has been divided into two major categories: Pulse Techniques and Phase Techniques. For the pulse techniques, a load was connected to a test cell through an appropriate switch so that the current was suddenly increased from zero to the required value. These values changed from C/2 to 100C on 4 Amp-Hr cells. The phase techniques rely on the measurement of the shift in phase between the cell voltage and current. (TAB U62-4-5:33, Dec.1,1962).

5410

Gulton Industries, Inc., Metuchen, N.J.


A system was developed to measure the residual capacity of Nickel-Cadmium batteries by measuring the phase shift produced by the cell. The system was calibrated for three sizes of batteries. An average deviation of 2% is reported for manually cycled batteries. Results of the first stages of tests on batteries with various histories are given. Data is presented indicating a high correlation between residual capacity and resistance measured during a short high current pulse. A device was designed to measure resistance during the first few msec. of a pulse of several hundred amperes. This device will provide a means of measuring current when a load of about 1/2 milliohm is connected across a cell for a short time. (TAB U63-1-4:31, Feb.15,1963).

5411

Gulton Industries, Inc., Metuchen, N.J.


The variations of several electrical properties of nickel cadmium cells with state of charge were studied to determine the suitability of any of these for measuring state of charge. Three methods were originally proposed: measurements of ohmic resistance, microsecond transients and double layer capacitance. During the investigations two additional parameters were measured, a.c. impedance and phase shift. Double layer capacitance and a.c. impedance and transient behavior are not useful properties for determining state of charge. A phase shift system is described which when properly calibrated predicted state of charge with an average deviation of ±10%. Ohmic resistance measured under correct conditions showed a closer correlation to state of charge but is difficult to measure.

5412


Due to the fact that silver cadmium cells could be constructed entirely free of magnetic materials, a secondary silver cadmium battery was used on Explorer XII, a satellite launched in 1961 to study radiation and magnetic fields. A program was carried out at Goddard Space Center to determine the feasibility of using the battery in this space application. Major points of interest of this program are presented. The operation of the power system on Explorer XII is outlined and cycling data, telemetered from the satellite, are presented. The first application of a silver cadmium battery on a satellite was very satisfactory. While in flight, no deterioration of the battery power supply was observed. (STAR, 1:13, Jan.8,1963).

5413


In Russian. Describes an arrangement for "forming" (i.e., subjecting to charge-discharge cycles) a station battery which has been in storage, using the normal motor-generator type of charger. (Elec.Eng.Abs.,66:1820, Feb.1963).

5414


The Missile and Space Division of the General Electric Company maintains a functional group which is responsible for
development of battery power supplies for space vehicle application. This group has developed battery power supplies for numerous space programs such as Thor, Atlas, and Titan nose cones, and for various experimental re-entry vehicles. The types of batteries used are described. Specific battery types were selected for use in order to satisfy the systems power requirements in R&D and operational re-entry vehicles, orbiting re-entry vehicles, and satellite vehicles of one- to ten-day orbit duration. (Astron.Infor.Abs., 7:70,498, Feb. 1963).


In Czechoslovakian. A critical discussion of the state of the storage battery industry in Czechoslovakia, in which shortcomings due to the shortage of special literature and due to the empirical approach in manufacture are disclosed. Principal developments abroad are described. (Elec.Eng.Abs., 66:4866, May 1963).


Studies to determine the most satisfactory methods for achieving low temperature operation of batteries.


New cathode-anode couples using non-aqueous electrolytes are investigated for use as possible secondary batteries. A lithium anode is used with either a silver chloride or nickel chloride cathode in an electrolyte consisting of propylene carbonate, aluminum chloride and lithium chloride. Electrode reactions are studied in detail.


Chemical reactivity rate determination was directed toward improving precision and reliability. Data are presented showing the effects of several variables studied during this period. A plastic version of the exploratory research cell which will accommodate the compartmented liquid anode retainer was fabricated. (TAB U65-1-1:22, Jan.1,1963).


The rechargeable electrochemical system Zn/KOH/HgO-Ag has been investigated from the viewpoint of aero space requirements. Individual study phases were used to evaluate cell components. Exploratory research cells were used during positive and negative electrode charge-discharge experiments.


A program directed toward demonstrating the feasibility of miniaturizing the liquid ammonia activated cell is reported. The liquid ammonia activated cell, utilizing a reducible organic compound at the cathode and a light, active metal anode has the theoretical capability of meeting the energy requirement. The solvent for the system, liquid ammonia, satisfies the temperature requirement. (TAB U63-2-4:16, May 15,1963).
battery on a satellite was very satisfactory; in flight, no deterioration of the battery power supply was observed.

5422

One Ag electrode containing Ag$_{110}$ and 3 other nonlabeled Ag electrodes were used as the positive plates in a cell. Cells were stored in charged and in discharged states. Cells with 5 negative plates, one of which contained Zn$_{65}$, were also prepared. During storage, the nonlabeled electrodes of the cells stored in the discharged state became contaminated with isotopes to a higher degree.


5423

A final report is presented covering an investigation of the most direct and systematic approach in selecting the most promising materials for the development of secondary batteries for space applications with higher capacities.

5424

Starting from silver oxide, a method of preparing positive plates without any grid has been worked out for a silver-oxide-zinc battery. The method is based on the fact that, on heating, silver oxide decomposes at a relatively low temperature to form silver which sinters to form a porous skeleton. The procedure thus eliminates one step (production of powder) in the conventional technique of production of anode plates using silver powder. The merits and demerits of the new procedure and the practical aspects of production are presented.

5425

The latest state of the art of three hermetically sealed rechargeable battery systems (nickel-cadmium, silver-cadmium, and silver-zinc) is presented. The use of these system energy storage devices in satellites and other space vehicles is discussed. Subjects covered include (1) cell reactions, (2) theoretical and practical energy densities, (3) construction features, (4) performance data, and (5) further areas for investigation. (Astron. Info.Abs., 7:70,501, Feb.1963).

5426

In Russian. Transl. (DSIR)NLL M. 3637. order from OTS or SLA.

In an investigation of the effect of different current forms on the electrolysis of zincate solutions it was shown that no zinc dendrites are formed during electrolysis with asymmetrical alternating and pulsating single-half-cycle currents under appropriate conditions. It is shown that the charging of nickel-zinc accumulators should only be performed with a pulsating single-half-cycle current at a frequency of 50 c./s. The possibility of employing the electrolysis of zincate solutions with pulsating currents in the electroplating and electrometallurgy of zinc is noted. (Tech.Transl., 9:265, Feb.15,1963).

5427

A prototype unit of the self-limiting battery charger was completed and has operated satisfactorily.

5428

Nickel-cadmium batteries are described for use in the Orbiting Astronomical Observatory satellite. The electrical design of the battery package consists of three strings of 22 cells each. One string will operate the equipment while the two redundant strings are available as standby batteries, which increases the reliability of the total battery package. When the operating battery falls below 22.0 volts,
one of the standby batteries is switched into operation. Electrical and environmental tests of the battery package indicate a probability in excess of 99% that the battery will perform its function for the prescribed 7000 cycles. (STAR, 1: 13, Jan.8, 1963).


The specific surface, S, of the electrodes in a Pb battery was evaluated with the aid of 

\[ S = 1.52 \times 10^2 \left( 1 - \frac{P_1}{P_0} \right) \]

where \( P_1 \) and \( P_0 \) are the radioactivity of PbSO4 solution at the end and at the beginning of the experiment respectively. (Chem.Abs., 58:222S, Jan.7, 1963).


The sixty cells of each of three sizes (10 A.H., 50 A.H. and 100 A.H.) have been manufactured. The qualification tests of SCL-7504 have been successfully passed and all cells have been delivered.


Results of the assignments to develop and improve the hermetic seal and the operational temperature range of the nickel cadmium "space battery" are discussed.


Technical and operational problems encountered in achieving the purposes of the contract are described. In particular, problems of low production yields and their eventual solutions are discussed. A major step in improvement of finished battery yields was the replacement of the brass outer case by an epoxy resin covering that enhanced the ease of assembly and reduced the danger of shorting. Other problems encountered included determining the design of the silver shell to serve as container for the individual cells, determining the design of the seal and lead assembly for the cells, and accelerating and improving the control of, the cathode extrusion step of the process. Results of preproduction qualification tests are presented. The process and process control steps in manufacturing the battery are described. (TAB U62-4-1: 1, Oct.1,1962).


Discussion of generators, or pressure cartridges, that supply gas which forces stored electrolyte from sealed container into battery proper; details on system in which gas pressure developed breaks diaphragm and pushes directly upon electrolyte normally stored in coiled copper tube; propellant and battery systems developed by Unidynamics Div, Universal Match Corp are discussed. (Eng.Index, p.46, June 1963).


This paper describes the development of an improved rechargeable, nickel-cadmium battery for spacecraft. It was designed for the S-51 International Ionospheric Satellite, also known as the UK-1 or Ariel 1. Innovations including a ceramic-to-metal hermetically sealed case and pellon-plate separators are discussed. The six-ampere-hour, secondary battery selected for this satellite was an early product of the joint research and development program for battery improvement sponsored by NASA and industry. This battery incorporated the latest advancements in the state-of-the-art for spacecraft secondary batteries at the time of launch on April 26,1962. (STAR, 1:14, Jan.8,1963).

Investigations were made of the energy conversion mechanism in thermally activated ceramic-metal cells. Research was focused upon the Fe anode, Li borosilicate enamel-electrolyte and Ag cathode cell configuration. The cell operation temperature range was 450 to 700 °C with 600 °C being the most satisfactory. The Ag cathode functioned as a gas electrode which absorbed O. The enamel’s ionic conductivity increased with temperature and transferred O(--) from the cathode to the anode. Electric power generation resulted from the free energy of anode oxidation reaction. Chemical analyses of discharged cells indicated Li migrated in the electrolyte to the cell cathode. Recharging of cells was not successful due to the iron oxide stability; however, anomalous charge storage was noted at 450 °C. Cells made of more reactive anode materials were studied. (TAB U63-1-1:21, Jan.1, 1963).


The feasibility of electrolyte regeneration was proved by a continuous current-drain experiment of more than 100-hr duration. The initial electrolyte consisted of 120 cc 3.0M KOH solution. The total current-drain amounted to more than 80 amp-hr (at around 1.5v and 20 ma/cm²), which is equivalent to more than 3 times the discharge expected without electrolyte regeneration.

VII. ENERGY STORAGE
A. General Information


Materials have been tested which, in terms of weight basis, have storage capability five times greater than batteries.


Silicon and a number of refractory oxide mixtures were studied in an investigation of materials having the properties of high heat of fusion (weight basis) and melting temperatures ranging from 1600 °C to 2200 °K. These thermal energy storage (TES) materials were examined for usage in solar collector-thermionic converter electrical power systems employed in space vehicles. A series of screening tests for silicon containment materials were conducted and indicated that pyrolytic graphite, boron nitride, titanium boride and several other materials might be useful. Alternate TES materials in the form of eutectic oxides were uncovered which had heats of fusion near or better than silicon. Fabrication and sealing problems of the silicon container materials have shifted emphasis to the oxides. A system study was undertaken using the oxides as part of a solar thermionic electric power system. Calculated specific system weights ranged from 185 to 285 pounds per kilowatt with 4BeO-4MgO-Al₂O₃ and 3BeO-2CaO respectively. The higher operating temperatures possible using oxides was the major parameter resulting in specific system weights lower than that calculated for silicon earlier. (STAR, 1:13, Jan.8, 1963).


The results of a program to determine and analyze the potentialities of three candidate thermal energy storage materials are presented. The program consisted basically of three major tasks: (1) a materials compatibility study; (2) an experimental program to determine the physical and thermodynamic properties of energy storage materials; and (3) the design, construction and operation of a unit to measure the heat release rates and movement of the fusion front in thermal energy storage materials utilizing latent heat of fusion.


Supercritical storage offers most simplicity in operation, with inherent reliability and availability of system components.


The Aeromutronic Division of Ford Motor Co., has developed a testing technique for obtaining “test-to-failure” data on thermal batteries and other one-shot items.
included in the Shillelagh missile system.

5442

Capacitive devices are more attractive in general, but superconductive magnetic designs show promise in megajoule region.

B. Chemical

5443

In German. The papers, on energy storage problems, given to the United Nations Conference on New Sources of Energy, Rome, 1961, are reviewed. Many aspects of the subject are discussed: comparisons between the costs of storing energy in batteries and in fuel cells; the use, efficiency and expected improvement of fuel cells; the principles involved in the chemical conversion of solar energy to chemical energy; the use of metal hydride fuel cells; the chemical conversion and storage of concentrated solar energy for which the solar furnace is used for photochemical reactions. Finally, the general costs of storing energy in any form and delivering it are analyzed with particular reference to storage batteries and fuel cells.


5444

Discussion of a method of evaluating a proposed energy source system. The study is based on the use of a theoretical liquid-metal-fuel system incorporating a potassium-bismuth cell and solar cells. The equations necessary to permit optimum cell operating parameters with respect to system weight are derived. The liquid-metal cell is compared with a conventional storage-battery system for the same application by plotting minimum specific weight as a function of orbit altitude for each system. The comparison reveals that the liquid cell is potentially superior as an energy source for satellite applications where the orbit period is less than 24 hr.


C. Electromagnetic

5445

An inductance coil made of superconducting wire, maintained at the temperature of liquid helium, is considered as a means of electrical energy storage. A method is described for obtaining an effective d-c output from discharge of such a coil. Optimization of the coil design for maximum energy storage yields energy-per-unit-volume figures in the range of 2 x 10^8 to 2 x 10^9 joules/m^3. The energy-per-unit-weight is comparable to that of batteries. The chief advantage of inductive energy storage is the capability of providing a power output greatly exceeding that of a battery of the same weight.


VIII. ENERGY SOURCES

A. General Information

5446

Experiments on the photolysis of nitrosyl chloride in CCl4 solution with un- concentrated sunlight showed that quantum yields and amount of energy stored with concentrated light were only 1/10 of that stored with concentrated light. Therefore, it has been shown that concentrated light considerably increases the output of a photochemical reaction. The results obtained with un-concentrated sunlight may be expressed in terms of the photodissociation of nitrosyl chloride and of the recombination of the photoproducts, NO and Cl. The pressure rise upon exposure to light rapidly approached a steady state. The location of the steady state was governed by the speed of the back reaction. Once the steady state is established, the gas is generated only as fast as it is consumed by the back reaction. On the other hand, if the gas were withdrawn continuously to feed a nitrosyl chloride fuel cell, the steady state would be upset and the gas would be generated at the rate at which it is generated in the approach to the steady state in experiments.


B. Nuclear

1. General Information

5447
The Atomic Energy Commission is reviewing the SNAP program because of anticipation of rapid growth in the nuclear space effort and in reaction to complaints of sluggishness in developing space nuclear power.


Possible types of nuclear reactors and energy converter suitable for the generation of power in space are surveyed. Estimates of probable performance are given.

S450 Martin Marietta Co., Nuclear Division, Baltimore, Md.

SNAP PROGRAMS-UPPER ATMOSPHERE EXPERIMENTAL RE-ENTRY STUDY, by W. Hagis, V.P., Apr.1963. (ND-P-2953) (Final Summary Rept.).

An experimental flight test program was conducted as part of a program of safety analyses of SNAP generators designed for space use. This report covers the analyses concerning the re-entry of the telemetry capsule, location of downrange aircraft, type and function of instruments and optical data reduction techniques.


Description of techniques for the direct static conversion of the intrinsic energy losses of a reactor to electricity. The physical processes involved in the conversion of gamma photons, thermal neutrons, and fast neutrons are discussed, as is a technique for the production of additional power by replacement of a reactor passive shield by an active shield. Possible emitter materials for neutron conversion are tabulated. (Intern.Aerospace Abs., 2:62-8867, Sept.1962).


The nuclear electric power plants now in use or in development are described to indicate the current capabilities and project future requirements. The Snap-2 and the Snap-8 power sources are discussed along with the possible effects of the space environment on these systems. The estimated power requirements through 1967 are given, and the possibility of fulfilling these requirements with advanced systems, such as thermionic converters, is considered. (STAR, 1:14, Jan.8,1963).


Two entirely different types of systems are being developed with SNAP designations. One type involves using power produced by small nuclear reactors, the other applies power produced by the heat from radio-isotope decay.


ENERGY CONVERSION, by C.E. Crouthamel and others. (ANL-6596(p.201-210)).

Research concerning the conversion of nuclear energy to electricity by use of regenerative emf cells and by thermoelectricity is reported. (Nuclear Sci. Abs.,17:14120, May 15,1963).


One part of the research program is concerned with research and development into methods for using the energy of fission and nuclear radiation to produce electricity directly, rather than through the heating of gases or steam to power a turbogenerator. Much of this work is directed toward compact power generators for the nation's space exploration effort.

2. Isotopes


With the technology sound and growing, and units already built for missions ranging from 120 days to 5 years, the designer can plan space application of isotopic systems.

S457 Chance Vought Corp., Dallas, Texas.

A technical and economic feasibility study was made in order to investigate the use of radioisotopic power as an energy source for remote area heating. Consideration was given to units for a rated output of 50,000 and 300,000 Btu/hr. Designs are presented for a number of feasible systems. The economic study revealed that a Nuclide heat unit can compete with conventional heaters in remote locations where conventional fuel logistics add measurably to the over-all heating costs and where long lifetime, highly reliable units are required. (Nuclear Sci.Abs., 17:3256, Feb.15,1963).

5458

Improved estimates indicate that the power needed for satellite-to-home receiver broadcasting is lower than previously believed - we are now confident a SNAP-8-powered satellite could cover an area seven times the size of the U.S.A.

5459

In Polish. The generator was designed for the USA Atomic Energy Commission. It found wider application in coastal navigation, meteorological, communication relay stations etc. They may be driven by different isotopes according to the application. In the prototype a thermal source 210Po was used. At the time of the half life the following data existed: radiation source 2100 c, energy (thermal) 69W, electrical energy 4 W. The temperature of hot and cold junctions was 62°C and 116°C respectively. The thermoelectric unit is described as well as application of SNAP-3 for navigational purposes. (Elec.Eng. Abs.,66:2790, Mar.1963).

5460

This is a brief announcement and description of the SNAP III thermoelectric conversion device, the energy for which is derived from radioactive polonium 210.

5461
Morse, J.G. ENERGY FOR REMOTE AREAS.


Generators fueled with radionuclides are supplying power in small terrestrial and space systems.

5462

Reviews the fundamental characteristics of power sources in which the decay heat of a radioisotope is converted into electricity by some direct energy conversion device - a thermoelectric converter in present devices. Some work carried out in the U.S. Atomic Energy Commission's SNAP Program is described, including experiments to study operational safety, and particular sources developed for the Transit and communications satellites and for the Surveyor lunar probe.

5463

Some general details are given concerning the production of strontium 90, also the uses to which it is put.

5464
Sandia Corp., Albuquerque, N.Mex.

A METHOD FOR DETERMINING THE CURIE LOADING OF Kr85 IN NUCLEAR BATTERIES, by Alex Thom. 19p., Jan.8,1960. (Tech. Memo 381-59 (16)).

This report describes a calorimeter which is used to determine the amount of Krypton 85 (in curies) in a nuclear battery. The construction of the calorimeter is described, and a sample measurement is included.

5465
Sandia Corp., Albuquerque, N.Mex.


The nuclear battery is a low-current, high-voltage, one-cell device with a shelf life of more than 10 years. The battery makes use of a radioactive, beta-emitting isotope to supply currents of the order of 10^-10 amperes and voltages of the order of thousands of volts. The nuclear battery is essentially a constant current device and will maintain approximately the same current either shorted or at thousands of volts.

5466
U.S. Air Force Special Weapons Center,
Kirtland AF Base, New Mexico.


Plutonium fuel capsules, designed for use in a thermoelectric SNAP device, were exposed to high-temperature oxidizing environments to evaluate the effects on capsule integrity and to determine the quantity and characteristics of alpha activity released during destruction of capsules.


In German. Discusses the production of electrical energy from radioactive sources directly to produce high-voltage, low-current supplies; and indirectly by the use of secondary emission, contact potential, semiconductor, photoelectric and thermoelectric devices to produce energy at low voltages. (Elec.Eng.Abs., 66:2509, Mar.1963).

3. Fission Reactors


Combining Snap systems will offer the designer various building blocks, with power to 43 kwe.


A typical fission-electric cell is described, in which a very thin layer of fissionable material covers a cylindrical cathode and a second concentric cylinder acts as an anodic fission-fragment collector. Continued open-circuit operation of the cell should lead to a buildup potential of 4 x 10⁶ volts. Among the problems to be solved is unwanted electron emission. The research program being carried out on the cell is described together with some experimental results; a voltage of 810 volts has been obtained. An analysis of the cell performance is given. In-pile experiments and high-voltage experiments now in progress are described. (Nuclear Sci.Abs., 17:7448, Mar.15,1963).


Description of the operation and specifications of nuclear-powered electric generators that are at present under development to provide auxiliary power for space vehicles. A table of space power requirements is included, and the various SNAP reactor power units are discussed and illustrated. (Intern.Aerospace Abs., 3:A63-14364, May 1,1963).

4. Fusion


To get power from nuclear fusion reactions a low pressure gas of heavy hydrogen needs to be heated to temperatures in excess of 100,000,000°K and held in place by magnetic forces for at least a tenth of a second or so. Reaching the required temperature seems not as difficult as containing the resultant plasma for a sufficient time. Plasma instabilities, however, permit it to escape from magnetic confinement. These instabilities fall into two classes, hydromagnetic instabilities and microinstabilities. The first class arises from the electrical and fluid properties of a plasma, without considering its detailed structure; the second class is caused by anisotropies in the distribution of the velocities of the particles in a plasma. Although no fusion device is completely free of such instabilities, considerable experience can be gained on how to control them. One guideline seems to be to keep the plasma pressure small compared with the pressure exerted on it by the confining magnetic field; another is to keep the particle-velocity distribution close to thermal equilibrium. Toy Top, an experimental fusion device of the mirror-machine type, which comes close to satisfying these criteria, can achieve ion temperatures close to the thermonuclear range, for only 0.1 millisec because of residual instabilities. (Nuclear Sci.Abs., 17:7448, Mar.15,1963).

5472

General Electric Co., Research Laboratory, Schenectady, N.Y.


Although fusion power has not yet reached the stage of proven technical feasibility,
it represents a challenging research opportunity for the electrical industry. After the primary goal of a self-sustained and controlled thermonuclear reaction has been achieved, there will remain the equally difficult task of progressing from laboratory demonstrations to practical and economical power plants. The electrical approach to thermonuclear power which is based upon the ideas of magnetic containment and electrical heating is attractive. Several ingenious embodiments of this concept show considerable promise. It may, however, be necessary to obtain a more complete understanding of the properties of high-temperature plasmas before a self-sustained reaction can be achieved. A fundamental problem in fusion research is that of handling the large quantities of electrical energy needed in the experiments. Recent progress in the design of mechanical switches, capacitors, and ignitrons is discussed. Capacitor banks being used for fusion experimentation at the General Electric Research Laboratory are also described. (Nuclear Sci.Abs.,16:32481, Dec.15,1962).


5474 Jephcott, D.F. THE SALZBURG CONFERENCE ON PLASMA PHYSICS AND CONTROLLED NUCLEAR FUSION RESEARCH (4th to 9th September, 1961). Contemp.Phys., 4:49-54, Oct.1962. The Conference was sponsored by the International Atomic Energy Agency and attended by over 500 delegates representing 30 countries; it was the first major international conference on controlled fusion research to be held since the 1958 Geneva Conference. This review describes some of the new aspects of a subject in which considerable progress has been made during these last three years, chiefly in the heating of plasmas and their containment by magnetic fields, since it is along these lines that it is hoped to solve the problem of obtaining useful power from the fusion of light nuclei.


In German. A review of methods that according to the present state of knowledge have prospects, in combination with nuclear reactors, for direct production of electric energy is presented. These methods depend on the principles of thermoelectronic, thermelectric, and magnetohydrodynamic generators as well as fuel cells. The chief mode of action of conceivable instruments based on these methods is explained, the state of research is explained by examples from the literature, and the prospects for application are discussed. (Nuclear Sci. Abs.,17:20681, June 30,1963).


Consideration of a class of hypothetical fusion reactors which makes use of an externally applied confining magnetic field. The problem of large output, possible methods for reducing the economic power output, implications of superconductivity, and the pilot-plant question are covered. (Intern.Aerospace Abs., 3:A63-14052, May 1,1963).


Discussion of some aspects of the power balance and the eventual economics of fusion reactors. Specifically covered is a deuterium-tritium (DT) mirror-machine type of reactor, although wider applicability is indicated. Based on present theory, DT mirror machines can be envisaged which would produce a positive balance against known energy-loss mechanisms. The following conditions must be met: (1) the plasma must be stably confined in a mirror machine of large aspect ratio; (2) the several transport coefficients which determine the rate of particle loss by collisions, and the rate of energy transfer between energetic ions and colder electrons, must not deviate seriously from the presently accepted theoretical values; and (3) particle-

5478
Princeton University, Plasma Physics Laboratory, Princeton, N.J.

Lectures are presented on the interest in thermonuclear power production, various considerations concerning fusion reactors, and power production estimates. (Nuclear Sci. Abs., 17: 955, Jan. 15, 1963).

D. Solar Collection and Concentration

5479
Analysis and computer studies show that collectors of other than paraboloidal conic sections of revolution, used for solar concentrators, can achieve sufficient intensities to produce emitter temperatures required for satisfactory thermionic energy conversion. Lightweight solar concentrators of any conic of revolution are formed without masters by inflating and stretching aluminized mylar film prior to foam rigidization. The mathematical analysis of second-degree conic concentrators is presented. The fabrication techniques and optical performance tests used are described. A mosaic method of manufacturing very large, low-cost concentrators is investigated. (Nuclear Sci. Abs., 17: 9129, Mar. 31, 1963).

5480
Barber, R.E., Mullaney, J.E. and Bailey, R.N.

A generalized weight estimate of the solar concentrator, heat receiver, support and deployment structure, and orientation system is presented for the power range 1 to 25 kw. A weight estimate of the combined power unit and radiator is presented for four example solar energy space power systems over the power range considered. The four example systems are (1) rubidium, Rankine cycle-turbine prime mover; (2) biphenyl, Rankine cycle-turbine prime mover; (3) steam, Rankine cycle-free piston prime mover; and (4) xenon, Brayton cycle-turbine prime mover. (Astron. Info. Abs., 7:70,560, Feb. 1963).

5481
Experimental calibration of a rigid solar collector is described. Evaluation of the geometry by optical inspection, of energy collection by calorimeter measurements, and of energy intensity by radiometer tests, is discussed. The effect of necessary accessories on the concentrator performance is presented. These accessories include the tracking system, vacuum-chamber window, and focal-plane mounting hardware. The effects discussed include: determination of collection efficiency as a function of misorientation angle, from 0 to 24 minutes misoriented; transmissivity losses and focused-energy distortion introduced by vacuum-chamber windows; and efficiency as a function of axial position. Flux distribution results, in planes perpendicular to the optical axis and on cylinders around the optical axis, are discussed. Two methods of flux distribution determination are utilized and compared. These are the incremental-energy method using a water calorimeter, and a point-by-point method using a radiometer. (Nuclear Sci. Abs., 17: 9131, Mar. 31, 1963).

5482
Boston University, Department of Chemistry, Boston, Mass.

The report describes X-ray structural studies of six different substances: Aluminum dodecaboride, AlB12; ammonium 12-tungstocobaltocobaltiate, (NH4)7(Co2CoW12O42); puridine-boron trichloride, C5H5N.BCl3; trimethylphosphine borane, (H3C)3P.BH3; pararosanilin perchlorate, (H2NC6H4)3C.C104; cobaltous chloride-dimethylsulfoxide, CoCl2((O13)250)3.

5483
Cobble, M.H.
ANALYSIS OF A CONICAL SOLAR CONCENTRATOR. Solar En., 7: 75-78, Apr.-June 1963.

The concentration that a conical mirror can theoretically attain is developed for two types of targets; a circular cylindrical target and a conical target. Under the assumption of a one-dimensional sun, the optimum mirror cone 1/2-angle is determined.
for both types of targets. At the optimum mirror cone 1/2-angle, the concentration, assuming a two-dimensional sun, is determined, and the optimum concentration in terms of mirror radii is found for both types of mirrors.

5484

The theoretical analysis of three types of heat exchangers for use with solar concentrators is developed. Under the assumptions of an incompressible inviscid fluid, constant energy rate input per unit area, and losses to the surroundings, an expression for the temperature field, and average exit temperature is given. An expression for a dimensionless temperature modulus, to aid in the determination of a fluid exit temperature, is derived and plotted for the three types of heat exchangers.

5485

The steady-state temperature distribution is solved for four target solids under the assumptions that the energy rate per unit area at the target surface is coordinate dependent, and that there are losses to the surroundings at the exposed target surface. The analysis includes a cylindrical slab and a sphere heated at the focus of a paraboloidal mirror, and a rectangular slab and a cylinder heated at the focus of a parabolic cylinder mirror. The general solution for each target solid is given for any type of distribution of target energy rate per unit area. In addition, an experimental target energy rate per unit area is assumed, and the exact temperature field is shown. A dimensionless external temperature modulus is plotted vs. a dimensionless coordinate for various Nusselt numbers, using the assumed target energy rate per unit area.

5486

The current interest in economic development of the arid, "under-developed areas", and the consideration of natural resources for meeting the energy needs of these areas, have led to new interest in possible processes for conversion of solar energy to electrical or mechanical energy. Developments of processes for this conversion (by low-pressure turbines, by thermoelectric, thermionic and photovoltaic convertors, and by Stirling engines) received emphasis in recent years, in part because of possible applications in space. The results of these developments have been improved prospects for application of these several processes to terrestrial power generation problems. These conversion processes require that energy be delivered to them at various temperatures and energy fluxes. Focusing solar collectors can be designed to deliver solar energy over a wide range of conditions to meet these needs. Focusing solar collectors are described and their performance noted, with particular emphasis on the interrelationship between the major design parameters: type of collector, temperature, concentration ratio, and reflector contour accuracy. Materials of construction are also discussed, with particular reference to the effects of materials properties on collector performance. Concludes with a commentary on the economics of power generation from solar energy, noting that the most likely applications are to small-scale power problems (i.e., up to 10kW), and that the prospects for power costs in the range of 5 to 10 cents per kWh are good. (Elec.Eng.Abs.,66:1337, Feb.1963).

5487

The current program is devoted to the design, fabrication, and preliminary testing of an all-metal petal of a 44 1/2-foot-diameter mirror. During this period, plating facilities were completed and checked for leaks with water and plating solution. The reflective inserts in the front-face master were completed. The polishable plastic surface of the large petal master has been proven experimentally by the model front-face reflective master which showed the practicality of such a system. A front-face skin was plated on the front-face master. It is now in the process of having the backing structure mold attached. A backing structure mold of plastic block foam was fabricated during this contract. The optical testing gear has been designed and is now in the process of assembly. A physical testing fixture has been designed and built. (STAR, 1:665-15971, Jly.8,1963).

5488
Progress is reported on the investigation of various types and methods of orienting systems to determine their limits and suitability for use with expandable flat-panel solar cell arrays in ground applications.

A survey of solar energy collector technology is presented to point out the major areas of accomplishment. One-piece electroformed nickel collectors that closely approach the theoretical concentrating ability have been fabricated. The unit weights of these collectors fall in the range of 0.90 to 1.00 lb/ft\(^2\) and, while their delivered energy per pound is low, they are capable of attaining higher absorber temperatures (over 4,000°R) than lighter collectors. The concentrating ability of the lighter reflectors, such as petal, Frensnel, inflatable, and inflatable-rigidized, falls in the range of 500 to 5000, which makes them suitable for lower temperature requirements (around 2000°R). The unit weights range from 0.03 lb/ft\(^2\) for the inflatable to 0.46 lb/ft\(^2\) for the Frensnel. The inflatable type delivers 1200 watts/lb at 2000°R while the petal models yield around 375 watts/lb. (STAR, 1:14, Jan.8,1963).

The meteoroid damage problem for space radiators is reviewed to point out possible approaches to the problem. Relations for predicting required thickness of armor protection are given for isotropic and uniform calculation procedures for design studies is proposed. The advantages of controlled radiator orientation to take advantage of the directional properties of meteoroids are also analyzed. (STAR, 1:15, Jan.8,1963).

A set of general graphical relationships has been developed for establishing the receiver-reflector area ratio which will provide the maximum useful heat delivery from a focusing collector. The method, applied to paraboloids and parabolic cylinders, gives the optimum area ratio in terms of incident radiation intensity, optical properties (including precision of reflector), and thermal loss rate. Use of the method for design and for evaluation of existing reflectors is illustrated; its use in economic optimization will be dependent on availability of adequate cost data.
An aluminum phosphate bonded mixture of nickel-chrome spinel and silicon dioxide completed 10,720 hours of endurance testing on a SNAP-8 finned-tube radiator segment. Flame-sprayed coatings of titania on SNAP-8 and Sunflower I sections completed 9870 and 9830 hours respectively. A fourth rig containing a SNAP-8 section with an aluminum phosphate-bonded mixture of silicon carbide and silicon dioxide completed 8600 hours of testing.

5496

Two new thin-film devices were described at a symposium at the Scientific Laboratory of Philco Corp., U.S.A. One shows transistor-like properties and is called an "edge-effect device"; the other can be used for solar-energy conversion. (Instrument Abs., 17:3500, June 1962).

5497

Apart from solar evaporation of Dead Sea brines, water heating is the major present practical use of solar energy in Israel and economics show it to be competitive with electric water heating. Solar research is concentrated on power production. Small units - up to 10kW - using inflated plastic collectors and a new organic vapour turbine of high efficiency are under development whilst an extensive research on solar ponds as large scale collectors for megawatt power production is being pursued. (Elec.Eng.Abs., 66: 1336, Feb.1963).

5498

The component development program of the Sunflower (solar energy conversion system) boiler/heat storage unit is presented. The design analysis conducted and the small-scale experimental investigations performed are described and their results given. The performance obtained on tests of full-scale demonstration units is discussed. Design considerations and weight estimates for the flight-weight unit are presented.

5499
United Aircraft Corp., Hamilton Standard Division, Electronics Department, Broad Brook, Conn. MODULAR DESIGN OF IMPROVED SOLAR CONVERTERS, September 1 - November 30, 1962, by W.J. Moriarty. 36p., illus., Nov.30,1962. (USR 2650) (Q.Prog.Rept.6) (Contract DA 36-039-sc-87461).

Solar cell shingle specification defining mechanical and electrical requirements. Design considerations for modified shingle assembly. Wiring schematic which provides for output of 7.75, 15 1/2 and 31 volts. Investigation of material, module and array concepts continued for special weapon type solar array.

5500

In German. Some basic American results in the field of utilization of solar energy are discussed with a description of an experimental plant; consideration is given to the seasonal and climatic factors involved in the construction of such a plant. (J.Appl.Chem.Abs., p.1-118, 1958).

IX. REGULATION AND CONTROL

5501

Factors which affect the accuracy of thermoelement AC-DC transfer devices are discussed, and the limits for accurate use are evaluated both for low and high frequencies. Technique for high-accuracy transfers, using reversals, is described.

5502

The report is concerned with the solution to the problem of utilizing power from unconventional sources. The method considered would utilize only one low-voltage high-current source, switch the current, pass it through a step-up transformer and utilize the output either in ac form or rectify it for dc applications.

5503
Research continued on voltage regulation and power stability in unconventional electrical generator systems. Test data on the internal impedance characteristics of a fuel cell are presented. Steady state volt-ampere characteristics of both thermoelectric and thermionic generators are given. An analysis of series-parallel switching methods of voltage control is included. Progress to date in the experimental investigation of efficient power conversion circuits using power transistors and silicon controlled rectifiers is given. The principle of a new, three-phase, static inverter is demonstrated by means of a model circuit. Static inverters are replacing rotary inverters for dc to ac conversion in aircraft, missile, and satellite electrical power systems. Where sinusoidal output is required, there is a design conflict between efficiency and waveform. The new circuit retains the efficiency of switching, but switched portions of the input are combined so as to approximate a sinusoidal output, thereby minimizing filter requirements. Controlled rectifiers are used because they are available in higher power ratings than transistors. The evolution of the new circuit from the basic parallel inverter circuits is traced. A multiwinding transformer (suggested by Toffolo of NRL) is used to obtain a three-step approximation to a sine wave. Primary turns in the ratio $\sqrt[3]{3} : 3 : \sqrt[3]{3} + 2\sqrt[3]{3}$ theoretically eliminate all harmonics up to the eleventh. The model circuit, constructed with turns in the ratio 1:3:4, exhibits even better waveform because of the filtering effect of the commutating capacitors. A simple criterion for successful commutation is established: the dc bus voltage must be greater than zero when each gate signal is applied. The main advantage of the new circuit is the reduction of filtering necessary for acceptable waveform. The principle may be employed with more switching elements to obtain even better waveform, but the increased complexity is not considered worth the gain. Another advantage of the circuit is that it is inherently a three-phase circuit, rather than three single-phase circuits, which promises construction economies and better performance under unbalanced load.


This paper assesses the problems of specifying and providing overload protection for solid state power supplies, with particular emphasis on military applications.

Minneapolis-Honeywell Regulator Co., Honeywell Ordnance Division, Hopkins, Minn.

The purpose of this contract is to investigate all known approaches and to determine the optimum methods of converting low voltage d-c power to higher voltage more useable d-c or a-c power for operating military electronic equipment. The most feasible methods of converting the low output voltages of thermoelectric, thermionic, solar cells, fuel cells or other source voltages in the range of 0.1 volt to 1.5 volts will be determined.

U.S. Naval Research Laboratory, Washington, D.C.

The principle of a new, three-phase, static inverter is demonstrated by means of a model circuit. Static inverters are replacing rotary inverters for dc to ac conversion in aircraft, missile, and satellite electrical power systems. Where sinusoidal output is required, there is a design conflict between efficiency and waveform. The new circuit retains the efficiency of switching, but switched portions of the input are combined so as to approximate a sinusoidal output, thereby minimizing filter requirements. Controlled rectifiers are used because they are available in higher power ratings than transistors. The evolution of the new circuit from the basic parallel inverter circuits is traced. A multiwinding transformer (suggested by Toffolo of NRL) is used to obtain a three-step approximation to a sine wave. Primary turns in the ratio $\sqrt[3]{3} : 3 : \sqrt[3]{3} + 2\sqrt[3]{3}$ theoretically eliminate all harmonics up to the eleventh. The model circuit, constructed with turns in the ratio 1:3:4, exhibits even better waveform because of the filtering effect of the commutating capacitors. A simple criterion for successful commutation is established: the dc bus voltage must be greater than zero when each gate signal is applied. The main advantage of the new circuit is the reduction of filtering necessary for acceptable waveform. The principle may be employed with more switching elements to obtain even better waveform, but the increased complexity is not considered worth the gain. Another advantage of the circuit is that it is inherently a three-phase circuit, rather than three single-phase circuits, which promises construction economies and better performance under unbalanced load.
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# DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS


A collection of references from various sources covering the current literature on thermoelectricity, thermionic emission, photoelectric processes, magnetohydrodynamics, electrochemical processes, energy storage, and energy sources.

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| 2. Thermoelectricity - Bibliography |
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