Rare-Earth Information Center NEWS

AMES LABORATORY

Iowa State University, Ames, Iowa 50010

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Volume II | June 1, 1967 | No. 2

RENO TECHNICAL STAFF — Front row from the left are Dr. T. A. Henrie, Dr. B. Porter, R. E. Lindstrom, E. Morrice, M. M. Wong, D. J. Bauer, J. O. Winget, K. G. Broadhead and H. H. Heady. In the back row from the left are D. H. Baker, J. D. Marchant, J. E. Murphy, J. P. Bennetts, K. R. Stever and A. B. Whitehead.

U.S. Bureau of Mines—

Reno Rare-Earth Metallurgy Group

As part of the U.S. Bureau of Mines metallurgy research program, the Reno Metallurgy Research Center in Nevada, under the direction of Dr. T. A. Henrie, is conducting research focused on chemical processing and electrometallurgy of the rare-earth elements.

The Chemical Processing Group, headed by R. E. Lindstrom, is currently engaged in ore processing and solvent-extraction investigations related to the recovery and separation of rare earths.

J. O. Winget's laboratory is responsible for development of processes for converting refractory rare-earth minerals to recover rare-earth mixtures. At present, this section is also working on the recovery of europium from complex rare-earth sulfate mixtures by reduction-leaching techniques.

D. J. Bauer is investigating the selective extraction and separation of rare earths from mixtures with nitrogen-based extractants. Promising systems developed in bench-scale studies are further evaluated in multistage equipment.

Electrowinning of rare-earth metals and electrotransport studies are basic programs carried out under the general supervision of M. M. Wong. E. Morrice and E. S. Shedd, with the assistance of J. D. Marchant, J. E. Murphy, and J. P. Bennetts, are investigating the electrowinning of high-purity rare-earth metals from the oxides dissolved in fluoride melts. Currently, gadolinium metal is won at 1400°C, and pound quantities of neodymium are being prepared for metallurgical evaluation.

Complementary to the electrowinning studies, reaction rates between rare-earth metals and electrolytes are being measured by D. H. Baker, Jr., and Bernard Porter.

Electrotransport techniques are being developed for preparing ultrahigh-purity neodymium and praseodymium metals by solid-state electrolysis. As a further effort, investigations are in progress on the

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Rare Earthers Around The World

MRS. C. E. LARSON MRS. F. H. SPEDDING

W. C. KOEHLER
ORNL
Conference Chairman

A. G. HORNEY
AF Office of
Scientific Research

A. M. WEINBERG
Director, ORNL

CONFERENCE BANQUET HEAD TABLE

6th RARE EARTH

PROLOGUE

The Sixth Rare Earth Research Conference was held at Gatlinburg, Tenn., in the foothills of the Great Smoky Mountains. Over 250 participants attended the meeting, and of these about 25 were from foreign countries. A total of 80 papers, 11 of them invited, were presented.

We believe that most of the conferees felt it was an excellent conference in keeping with the standards set in the previous rare earth conferences. We of RIC wish to thank Chairman Wally Koehler, his committee and staff for their efforts, thoughtfulness, and kind hospitality which made this one of the most successful conferences.

Thirteen sessions were held throughout the three-day meeting on solid state physics, chemistry, metallurgy and industrial aspects of the rare earths. Summaries of the papers are presented elsewhere in this issue.

On Thursday the conferees had a choice of spending a day visiting the Oak Ridge National Laboratory, taking an invigorating mountain trail hike or just loafing. Those who went on the hike found it to be a little more invigorating than they might have thought since the homeward bound trek, made in a driving snow storm, was mostly an uphill climb at about 6000 ft. above sea level.

On the first evening, a reception sponsored by the Nuclear Division of Union Carbide Corp., and

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SOLID STATE

Magnetic Properties

Two studies of the effect of pressure on the magnetic properties of rare-earth metals and alloys were presented. The first, an invited paper by R. Pauthenet, D. Bloch and F. Chaisse of the Electrostatics and Physics of Metals Laboratory, Grenoble, France, was a discussion of the effect of pressure on the magnetic ordering temperatures and the saturation magnetization of polycrystalline Gd, Tb, Dy and Ho metals, and of rare earth-iron garnets. In the second paper, also an invited one, D. B. McWhan of Bell Telephone Laboratories reviewed recent measurements of the pressure dependence of the Néel and Curie temperatures, and crystal structures. The materials studied included Eu, Gd, Tb, Dy and Ho, Tb-Y alloys, and a series of alloys with equal deGennes function values.

Another invited paper on magnetic properties reviewed investigations on the effect of *s-f* exchange in dilute alloys of rare earths. It was presented by K. Yosida of the Institute for Solid State Physics, University of Tokyo. He noted that *s-f* exchange interactions play a decisive role in determining the magnetic and electrical properties of the alloys.

Magnon dispersion relations in rare-earth metals from inelastic neutron scattering was the topic of the invited paper by H. B. Møller of the AEK Research Establishment Risø, Denmark, and

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MRS. A. M. WEINBERG

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Kansas State Univ.

F. H. SPEDDING
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MRS. A. G. HORNEY MRS. W. C. KOEHLER

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Vice-President
Union Carbide Corp.

I. S. HIRSCHHORN
Ronson Metals Corp.

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RESEARCH CONFERENCE

CHEMISTRY

CRYSTAL CHEM

The crystal chemistry of the rare-earth elements received a great deal of attention at this conference. J. S. Anderson from Oxford University, England, reviewed the non-stoichiometry and crystalline defects in rare-earth oxides, sulfides, selenides, tellurides and nitrides in his invited paper. He noted that the nitrides have a large concentration of defects, and that a random model to describe them is not plausible. In the chalcogenides there is a strong tendency toward maintaining local ordering. Because of these behaviors Anderson felt that an understanding of these materials should be helpful in furthering our knowledge of the defect state, especially if the experimental data, both structural and thermodynamic, can be correlated with the theoretical-statistical thermodynamics of solids.

The formation and structures of the AB_2 compounds, where B = Se, Te or Sb, were discussed by Wang and Steinfink. The crystal chemistry of the gold-rich rare earth intermetallic phases was described by Sadagopan, Giessen and Grant; and the ternary compounds which have the $CeCu_2$ type structure were reviewed by A. E. Dwight.

The chemical and electron-optical behavior of rare-earth oxide microspheres were presented by Hardy, Buxton and Willmarth. The structural features and similarities of the A, B, and C forms of

(Continued on Page 6)

INDUSTRIAL

The Conference Keynote Address was given by Howard E. Kremers, American Potash and Chemical Corp. It was the first time in the history of the rare-earth conferences in which an industrial representative gave the keynote address. We agree with the Conference Chairman and Committee that it was timely and appropriate.

The history of the rare-earth industry and the parallel rise in their production with various commercial developments was noted. A number of false ideas concerning the rare earths were exposed and classified. For example, many people believe gas mantles are no longer made; the truth of the matter is, as Kremers pointed out, "there are more mantles in service today than at the height of the old gas lighting era."

The rare earth industry has grown from a $2 million per year sales volume in 1946 to $15 million per year in 1966. It is interesting to note that while the dollar amounts have increased by a factor of 7.5, the volume in pounds sold has increased by only one-third over this same period (6 to 8 million pounds per year). The big increase in the dollar volume is due to the cost of producing high purity, separated rare earths for special applications such as phosphors, microwave devices and research. However, the total weight used in these devices is only about one million pounds.

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6th Metallurgy

The lead-off talk in the Metallurgy Session was an invited paper by Karl Gschneidner, Jr., Iowa State University, on problems and progress in rare-earth metallurgy. The primary problem in the field of metallurgy is that of obtaining high purity metals. This problem, which has been with us since the first rare-earth metal was made in the 19th century, will be always present because of the continuing demand for another significant figure in the metal's purity. Today we have the capability of preparing about 99.9% pure metals on an *atomic* basis with respect to all impurities, he commented.

The lack of purity in our presently available metals was also emphasized in several other papers, both in the Solid State Physics and Metallurgy Sessions. Gschneidner also mentioned several other important problems in the field of metallurgy: the lack of reliable phase relationship studies; absence of any fundamental research on the mechanical behaviors; and a lack of understanding of the crystal structure sequence in the metals and the intra-rare earth alloys.

Other papers were concerned with the effect of α-particle radiation on the electrical properties and the α to γ transformation of cerium (Elliott, Miner and Clinard); the metallographic study of the allotropic phase transformations in cerium (Koch and McHargue); and phase diagram studies by several authors.

By use of beautiful color photomicrographs Koch and McHargue were able to study some of the transformation kinetics of the low temperature allotropes of cerium. Their anodizing technique for preparing the metal surface promises to be a useful tool in investigating cerium and probably most of the other rare-earth metals.

Alloy studies of the rare earth-lead systems were presented by Carlson, Schmidt and Diesburg (Y-Pb) and by O. D. McMasters (La-, Eu-, Dy-, and Yb-Pb systems). Investigations of lanthanide-iron group metal systems were discussed by O'Keefe, Roe and James (Ho-Fe) and Gebhart, Etter and Tucker (Ce-Fe and Ce-Ni). The last paper in this session dealt with the phase equilibria and thermodynamic studies of the Sm-Gd system (Yamamoto and Lundin).

6th OPTICAL PROPERTIES

The first Solid State Session opened with an invited paper by Hellwege, Hüfner, and Weber of the Institute for Technical Physics, Darmstadt. Hellwege presented a survey of the optical and magnetic investigations carried on in the Darmstadt laboratory: optical studies of erbium-, holmium- and dysprosium-iron perovskites, and dysprosium-aluminum perovskite; hyperfine structure studies of holmium ethlysulfate and holmium chloride; and magnetic susceptibility investigations of holmium ethylsulfate and several other compounds.

Results of an optical study of thin films of ytterbium were given by Okorie and Singh.

The invited paper in the Chemistry Session on optical behaviors, presented by P. N. Yocom of the RCA Laboratories, reviewed the state-of-the-art of laser behaviors of the lanthanide elements. Yocom discussed the inter-relationships between the important quantities needed for laser action. These quantities are the transition frequency, linewidth, dipole moment matrix element for the transition, and cavity properties. The di and trivalent rare-earth ions, in which laser action was observed were noted. In addition the transition which gives laser emissions, and

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Follow-up on CMN Thermometer

We would like to bring to your attention two additional papers on cerium-magnesium-nitrate thermometry (*RIC NEWS*, Mar. 1967).

In the first of these, R. B. Frankel, D. A. Shirley and N. J. Stone (*Phys. Rev. 140*, A1020 [1965] and *143*, 334 [1966]), redetermined the temperature scale below 0.006° K. using a nuclear orientation method. They found that the accepted temperature scale, based on magnetic susceptibility data is incorrect below 0.006° K.

The second paper is by R. P. Hudson and R. S. Kaeser who reported the use of isentropic demagnetizations in determining a temperature scale for the 0.002-5.0° K range (*Phys. 3*, 95 [1967]). These authors have made a detailed analysis and have discussed some of the inherent difficulties of CMN thermometry based on the magnetic behavior of this cerium salt at low temperatures. Hudson and Kaeser conclude that CMN is one of the most useful low temperature thermometers between 0.002 and 2.0° K.

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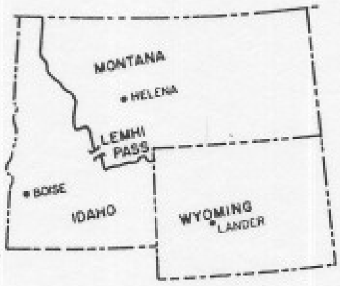
Rare Earths In the News



LEMHI PASS R.E. FIND UNDER DEVELOPMENT

The Lemhi Pass deposit of thorium and rare earths (*RIC NEWS* Vol. 1, No. 1) is reported by *Chem. & Eng. News*, Feb. 20, 1967 to be on the brink of intensive development. Sawyer Petroleum Co., Oatman, Arizona, and The Dow Chemical Co., Midland, Michigan, are working on the development of the deposits. Sawyer has acquired claims totaling 1280 acres and is collaborating with the Union Pacific Railroad in their development. Dow has leased 26 claims from Nuclear Fuels and Rare Metals, Inc.

An improved solvent extraction process for isolating thorium from the Lemhi Pass deposit has been developed by Dr. Ralph Borrowman of the U.S. Bureau of Mines in Salt Lake City. Although the process has not so far been put into commercial operation, it promises to be cheaper than the present method.

ZIRCONIA CLOTH

Union Carbide Corp., New York has announced the availability of yttria-stabilized zirconia cloth. The 25 x 25 cm (10 x 10 in.) cloth is available in two fiber sizes, 0.25 and 0.75 mm (10 and 30 mil) diameter.

The zirconia cloth may be used as: ablative materials for space ships during re-entry and for rocket engine insulators; catalyst supports; filter media; high temperature insulators; and gas diffusers.

Yttria is added to stabilize the high-temperature cubic form of zirconia, helping to the control the fiber diameter and assuring a continuous filament fiber. The thermal and chemical stabilities are also enhanced by the yttria additions.

CANADIAN APATITE

Multi-Minerals, Ltd., says that about 55 lbs. of rare earths occur in each ton of apatite rock concentrate obtained from its phosphate rock deposits at Nemegos, Ontario, Canada. Multi-Minerals is using chromatographic separations in its phosphoric acid production with an eye toward extracting the rare earths as by-products. There are an estimated 40 to 80 million tons of apatite in the firm's Nemegos deposits.

NEODYMIUM LIGHT

Dr. O. Braaten of the Royal Norwegian Council for Scientific and Industrial Research has informed us about a light bulb made of glass containing 10% Nd. This light bulb has been developed by Dr. O. Erämetsä of the Institute of Technology, Helsinki, Finland.

The "AIRAM" lamp produces light with very pronounced maxima in the range where the human eye is most sensitive, centered about

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INDUSTRIAL

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An Industrial Processes session was held with eight papers being presented. One paper dealt with direct chlorination of rare-earth ores at high temperature to yield a reasonably pure mixture of rare-earth chlorides only (Brugger and Greinacher). Four papers dealt with the separation and recovery of the individual rare earths from mixtures: liquid-liquid extraction (Elias, Sebenik and Smutz); ion exchange (Morton and James) and (Silvernail and Woyski); and recovery of cerium and lanthanum by ozonation of liquid solutions (Bauer and Lindstrom).

Three papers were concerned with metal preparation. J. L. Moriarty discussed metallothermic reductions on an industrial scale; Morrice, Shedd and Henrie talked about an electrolytic method of preparing the metals on a research scale; and I. S. Hirschhorn described several industrial electrolytic techniques for obtaining rare-earth metals.

Europium In Humans

The uptake, retention and excretion of inhaled europium oxide was studied by P. L. Ziemer, R. E. George, W. V. Kessler and J. E. Christian following accidental inhalation of irradiated europium oxide by two healthy adult males.

It was found that with initial body burdens of 87.7 and 53.6 microcuries in the two individuals, 84 and 92%, respectively, was eliminated in the feces in the first 48 hours after exposure. Small amounts of activity were also observed in the urine.

The material remaining in their bodies concentrated primarily in the lower half of the lungs and was only slowly eliminated. Biological half-times were 390 and 380 days

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PROLOGUE

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the conference dinner were held. Dr. Adrian H. Daane, Kansas State University, was the master of ceremonies.

The after-dinner speaker was Dr. Alvin M. Weinberg, Director of the Oak Ridge National Laboratory. He spoke on "New Vistas in Transuranium Research," which is primarily concerned with the production of the transuranic rare-earth elements. He noted that there are two methods which can be used to prepare these elements.

One, the leap-frog method, involves the bombardment of heavy elements with medium atomic weight nuclei (Ni, etc.) to produce nuclei which have atomic numbers of about 114 and 126. These are thought to have more stable nuclei than the elements of atomic number between 96 and 112. The entire transuranic series could be made, since radio-active decay would yield lower atomic number daughter products.

The second method involves high neutron fluxes of 10^{15} - 10^{16} neutrons/cm^2/sec. Thus by successive neutron capture, starting with Pu-242, it would be possible to produce annually gram quantities of californium (atomic number 98), 100 grams of curium (96) and milligram amounts of berkelium (97) and einsteinium (99). The problems such as heat, reactor design, fuel loadings and cost which are associated with this technique were also described.

Several announcements were made concerning future Rare-Earth Conferences. The Seventh Conference will be organized by Dr. J. F. Nachman, Solar Division of International Harvester, and is tentatively scheduled for November 1968 in Southern California. A conference in France is being organized by Dr. F. Trombe, National Center for Scientific Research, France, and is tentatively scheduled for April 1969. Further announcements concerning these meetings will be made in RIC News *as they become available.*

Dr. W. C. Koehler told us that copies of the conference proceedings may be purchased from him. The 740-page proceedings consists of preprints of the conference papers.

CRYSTAL CHEM

(Continued from Page 3)

the rare-earth oxides and some related compounds were described by P. E. Caro. Studies of mixed oxides systems were the topics of three other papers: the nature of the structures and equilibria in Eu-Ti-O system (McCarthy, White and Roy); the vapor pressure over Ce-Tb-O phases (Kordis and Eyring); and the phase equilibria, point defects and kinetics in the CaO-R_2O_3 and ThO_2-R_2O_3 systems, where R = La, Gd or Yb (Roy, Diness, Barry).

Other subjects discussed were concerned with point defects in rare-earth dihydrides (Libowitz and Lightstone); the structure of lanthanum dihydroxy chloride (F. Carter); the crystal structure of Yb_3S_4 and MnY_2S_4 (Chevalier, Laruelle and Flahaut); and the high temperature neutron diffraction study of the polymorphic structures of LaC_2 and YC_2 (Bowman, Krikorian, Arnold, Wallace, and Nereson).

CHEMISTRY — COMPLEXES

In an invited paper T. Moeller of the University of Illinois reviewed the current problems and progress in the studies of the coordination chemistry of rare-earth ions. He noted the present emphasis is on the structure of and the bonding within complex species, the thermodynamic stabilities of the complex, the properties which are associated with the 4*f* electrons, and applications that depend upon the particular properties of a complex.

Moeller pointed out that irregularities which occur in the thermodynamic properties of the complexes as the lanthanide ion is varied are not well understood and probably result from various contributions.

CHEMISTRY — SEPARATIONS

Advances in the chemical separation of the individual rare earths were given by several authors. Peppard and Mason discussed liquid extraction techniques and some of the problems associated with this separation method.

Papers by Powell and Burkholder, and by E. J. Wheelwright described ion exchange techniques for separation of Sm-Eu and Eu-Gd mixtures, and for purifying promethium, respectively.

The effects of geometry and mechanical agitation on the amalgam method for extracting europium from aqueous lithium citrate solutions were discussed by Goddard, Campbell and Onstott.

Several other papers describing separation techniques were presented in the "Industrial Processes" session, page 5.

CHEMISTRY — GENERAL

Three papers were concerned with the preparation of various inorganic compounds. E. L. Head described the preparation of some rare-earth sesquicarbonates. The preparation, characterization and thermodynamic properties of some $R_2C_2O_2$ compounds, where R = La or Nd, were presented by Butherus and Eick.

G. Brauer described a unique method for preparing rare-earth oxides at low temperatures (~400°C) by precipitation from fused salt mixtures. His data suggest that the B-form of Sm_2O_3, Eu_2O_3 and Gd_2O_3 is the stable form of the oxides at this temperature, rather than the C-form which heretofore was thought to be the stable modification.

The use of several methods to prepare divalent lanthanide ions as dopants in KCl was discussed by C. G. Kirkpatrick, but the attainment of the divalent state in the KCl hosts was realized only for samarium.

Lanthanothermic Reductions

The use of lanthanum as a reductant to prepare pure metals from their oxides is discussed in two recent papers. Europium, samarium, thulium and ytterbium have been prepared for the last fifteen years by the lanthanum reduction of the respective oxide. But it is only recently that lanthanum (and also yttrium in the case of beryllium) has been employed to prepare other metals, specifically beryllium and americium.

The former is discussed in a paper by T. T. Campbell, R. E. Mussler and F. E. Block, *Trans. Met. Soc.* 236, 1456 (1966) and the latter in a U.S. Atomic Energy Commission Report, UCRL-14513, by W. Z. Wade and T. Wolf of the Lawrence Radiation Laboratory in Livermore, California.

The preparation of these metals is made possible in both instances by the utilization of the high heat of formation of lanthanum oxide, the extremely low vapor pressure of both lanthanum and lanthanum oxide and the relatively high vapor pressure of beryllium and americium.

The reduction process is achieved by mixing lanthanum metal with beryllia or americia and heating the mixture in a high vacuum. An equilibrium, $La + MO_x = M + La_2O_3$, is set up, but since M is volatile it is removed from the reaction vessel and the reaction is driven to the right by virtue of Le Chatelier's principle. The volatile metal is collected on a condenser located in a cool portion of the furnace. Yields of about 90% in both instances and purities as high as 99.6% Be and 99.99% Am were achieved.

* * * * *

PROMETHIUM, atomic number 61, was discovered in 1947 by J. A. Marinsky, L. E. Glendenin, and C. D. Coryell in the fission products of uranium. The name, from Greek mythology, was derived from Prometheus, who stole fire from heaven and gave it to man.

SAMARIUM, atomic number 62, was discovered by Lecoq de Boisbaudran in 1879 and was named after a Russian mine official, Colonel M. Samarski.

Chinese Journal

An English translation of *Acta Physica Sinica* is now available on a regular basis from the American Institute of Physics under the title *Chinese Journal of Physics (Peking)*. The first issue contains four articles which may be of interest.

The papers deal with the wave functions of the f^4 to f^7 configurations, the magnetic transformations and structures of the lanthanide metals, the ferrimagnetic resonance of yttrium-ytterbium iron garnet, and the magnetization and ferrimagnetic resonance of yttrium-gadolinium iron garnet.

The wave function paper, although it contains information on the f^4 to f^7 configurations, lists the complete wave functions of only the f^4 state. Lesser amounts of information are given for the other states.

The paper concerning the magnetic structures and transformations discusses the stability conditions for the various magnetic structures of the lanthanides on the basis of the Landau theory of second order transformations. How well this approach to the problem works is difficult to determine, since the author makes no references or comparison to earlier work on the same subject by scientists such as Cooper, Elliott, Kaplan, Miwa, Nagamiya and Yosida.

It should be noted that the April issue of *Physics Today*, p. 69, mentioned that the red-guard cultural revolution in China has caused the suspension of publication of the original Chinese journal.

Lutetium was independently discovered by G. Urban in 1907 and C. F. Auer von Welsbach in 1908.

Space Mining?

The solar abundances of some of the lanthanides have been estimated by A. Righini and M. Rigutti, *Ann. d'Astrophys.* 29, 379-387 (1966). Their results are based on analysis of the spectra of singly-ionized lanthanide ions which have been identified in stellar atmospheres. The abundances relative to that of hydrogen being 10^{12} are listed below. Also given in the table are the abundances of the same elements in the earth's lithosphere.

R.E.	Solar Abundance[a]	Abundance in Lithosphere (w/o) x 10^4
Ce	60	45.5
Pr	28	6.25
Nd	85	24.5
Sm	42	6.75
Eu	9	1.15
Gd	13	8.2
Dy	10	6.0

[a] Relative to the abundance of hydrogen being 10^{12}.

The solar abundance estimated by Righini and Rigutti are in reasonable agreement with previous data based on analysis of chondritic meteorites. As the authors point out, their results, with one exception, seem to be systematically larger than those obtained from meteoritic analysis.

It is interesting to note when comparing the lanthanide solar abundances with those in the earth, that the relative amounts of the elements may be significantly different. For example, neodymium is approximately 40% more abundant than cerium in the stellar atmospheres, but cerium is about 85% more prevalent than neodymium in the earth's lithosphere. One note of caution should be made before such an analysis is extended very far: The error in estimating solar abundances is quite large.

AMES LABORATORY—

Pure Metals Preparation Group

METALLURGY GROUP — Standing from left are Wayne Paulson, Grad. Asst., Roger Stevens, Assoc.; Phil Vormelker and Ralph Pratt, both Grad. Assts.; and Rick Schmidt, Assoc. Metallurgist. Seated is Dr. O. N. Carlson, Group Leader.

The research activities of Metallurgy Group V are directed toward the preparation of metals of nuclear interest, and determination of the phase equilibria and mechanical properties of alloys involving one or more of these metals. Present emphasis is on vanadium, thorium, chromium and yttrium, with approximately a third of the total effort being devoted to the latter element.

Over the past few years processes have been developed for preparing high purity yttrium, thorium and vanadium in quantity and work is continuing on further improving these processes. The preparation of small amounts of the three metals in ultra-high purity, using an electrotransport technique, is currently being studied. This method has been successfully used to produce thorium of 99.999+ purity and is now being applied to other metals.

The migration velocities and diffusion coefficients of carbon, oxygen and nitrogen have been determined in thorium, yttrium and vanadium as a function of temperature and similar work is now underway on chromium and lutetium.

Alloy systems under investigation include the recently completed yttrium-lead system and the analogous yttrium-tin system now in progress. A study of the yttrium-carbon system is also nearing completion. The proposed phase diagram consists of three intermediate phases, one at the composition Y_3C, one at Y_3C_4 and the stable, high melting compound YC_2.

The effect of impurities or alloying additions on the mechanical properties of these metals constitutes the third area of interest to this group. While studies of this nature have been carried out in the past on yttrium and its alloys, present studies are limited to vanadium and chromium.

OPTICAL PROPERTIES

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the host materials (crystalline solids, glasses and liquids) were listed.

This broad and excellent review paper set the stage for the following papers. They dealt with: trivalent europium fluorescence (H. J. Borchardt); energy transfer in a doubly-doped (Ho^{+3} and Yb^{+3} ions) crystal (Esterowitz, Bahler and Noonan); optical properties of tetravalent dysprosium (Varga and Asprey); cathodoluminescence of lanthanide activated Y_2O_3 (Wickersheim, Buchanan, Weaver, Sobon, and E. E. Anderson); and the preparation and properties of europium-doped YVO_4 and $ABVO_4$ type compounds, where A and B are two different cations (Loriers and Heindl).

Crystal Structures

Rare-earth scientists working on borides, carbides, oxides, hydrides, nitrides, metals and intermetallic compounds may be interested in a recently published handbook. The second volume of *A Handbook of Lattice Spacings and Structures of Metals and Alloys* by W. B. Pearson, Pergamon Press, (1967), collates all of the structural data which has been published between 1955 and 1965.

Although the cost of the book may seem prohibitively high, $75.00, it figures out to about 5 cents a page (1450 pages). Since this monumental work so compactly brings together the crystallographic data by alphabetical listing and also by structure type, this volume is a valuable aid to those engaged in ceramic, metallurgical and solid state research.

Thermionic Properties

An extensive listing of the work functions and Richardson constants has been compiled by V. S. Fomenko. This tome, *Handbook of Thermionic Properties*, was translated from Russian and is available from Plenum Press in New York. The thermionic properties of the rare-earth metals, borides, germanides, oxides, silicides, sulfides, and tungsten-coated alloys are included.

In general the author has listed all the values he found for a particular material, and has made no attempt to critically evaluate these data. For most of the metals, however, he lists a value he believes to be the best, but he does not state his reasons for doing so. One or more references is given for each value, so the reader can easily refer to the original literature. A total of 473 references are included in this handbook.

MAGNETIC PROPERTIES

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J. C. G. Houmann and A. R. Mackintosh, both of the Technical University, Copenhagen. Results of studies on terbium metal and a Tb-10% Ho alloy over a wide temperature range were presented.

Another investigation on the neutron scattering from paramagnetic terbium at 660°K (390°C) resulted in a report on the energy distributions of neutrons scattered from a single crystal (Cable, Collins and Woods).

Several investigators reported on the magnetic characteristics of the rare earths. Problems studied were the magnetic properties of dysprosium (R. G. Jordan); the magnetic and crystallographic characteristics of PrH_x, where x varies from 0.99 to 2.57 (Mader and Wallace); and the magnetic behavior of rare-earth compounds with a singlet crystal-field ground state (B. R. Cooper).

Other studies reported were: the magnetic and electrical properties of some Yb-Sb intermetallic compounds (Bodnar, Steinfink, and Narasimhan); the magnetic properties and structures of RCo_3 intermetallic compounds (Lemaire, Pauthenet, Schweizer, and Silvera); the magnetic structure of a terbium-iron garnet at 4.2°K (Tcheou, Delpalme, and Bertaut); the magnetic behavior of the $ATbO_3$ compounds where A = Cr, Fe, Al, Co, Ga or Mn (Sivardiere, Mareschal, Quezel-Ambrunaz, de Vries and Bertaut); the frequency dependence of magnetic losses in holmium in the neighborhood of the Curie temperature (Gerstein and Olander); the permanent magnetic properties of YCo_5 powders (Strnat, Olson and Hoffer); and the existence of an antiferromagnetic phase in R_2Fe_{17} compounds (Weik, Susedik and Turner).

ELECTRICAL PROPERTIES

Three papers were presented in this area. The topics were: the electrical conduction and dielectric breakdown in evaporated films (300-6000 Å) of La, Ce, Pr, and Nd oxides (Fromhold, Foster, Harbuck and Mosley); the electrical resistivity and Seebeck coefficients along three crystallographic directions in thulium single crystals (Legvold and Edwards); and the electronic properties and band structures of rare earth-rich carbides (R. Lallement).

A related paper presented by K. Yosida is described on page 2 under "Magnetic Properties".

RESONANCE PHENOMENA

Four papers in the area of resonance spectroscopy were given. These dealt with the microwave absorption in dysprosium single crystals (Blackstead and Donoho); the temperature variation of gadolinium electron spin resonance spectra in cubic and axial crystals (Abraham, Boatner, Lee and Weeks); the electron paramagnetic resonance angular spectra of gadolinium in $R_2M_3(NO_3)_{12} \cdot 24H_2O$ single crystals, where R = La or Bi and M = Zn or Mg (Buckmaster, Dering, and Fry); and the nuclear magnetic resonance measurements in rare earth-group VA compounds of the NaCl-type (E.D. Jones).

An additional report on resonance phenomena was given by Dunlap, Dwight, Kalvius and Kimball, who investigated the temperature dependence of the Mössbauer hyperfine field in Ho-, Er-, Tm-, and Yb- gold compounds.

HEAT CAPACITY

Graphical analysis of low-temperature heat capacity data for some rare-earth metals was investigated by Morrison and Newsham, who stressed the advantages of this method as opposed to a standardized (computer) analysis. A lively discussion about the method followed Newsham's presentation.

Other research reported in this field was the heat capacity of scandium (Flotow and Osborne) and of $PrNi_2$ and PrBi (Dixon, Aoyagi, Craig and Wallace). Flotow and Osborne noted that for scandium there were departures from the usual low temperature heat capacity behavior. The suggested cause was impurities in the metal.

Dixon and co-workers analyzed their low temperature heat capacity results to determine the crystal field contributions.

GENERAL

A review of the current knowledge of some of the electric, magnetic and optical properties of the rare-earth metals was given in an invited paper by A. J. Freeman of the National Magnet Laboratory. The basis of the present understanding of these properties is the detailed *ab initio* energy band calculations of the metals' structures and Fermi surfaces.

Such calculations have shown that the free electron model is completely inappropriate for the rare-earths and consequently cast doubt upon the interpretation of any physical property based on that model.

Other topics covered in the solid state sessions were: the positron annihilation in rare-earth single crystals (Williams and Mackintosh); the luminescence of Bi and Eu in rare-earth compounds (R. K. Datta); the M series x-ray emission lines of the rare earths (A. F. Burr); the magnetostriction in dilute rare earth-iron garnets, specifically in gadolinium-iron garnet and dysprosium-yttrium-iron garnet (Clark, Rhyne, and Callen); the elastic moduli of gadolinium metal (Fisher and Dever); and the hyperfine fields in Sm, Eu, Gd, Tb, Dy, Ho, Er and Tm metals and in some of their compounds examined by a nuclear polarization technique (G. Brunhart).

RARE EARTHS IN THE NEWS

(Continued from Page 5)

5600 A. It is reported to lend decorative illumination to flowers, meat and pretty girls. The Finnish EXPO-67 display is completely illuminated with this type of Nd-lamp.

Reports, Brochures, Booklets

Pm-147 EVALUATED

Battelle Northwest Laboratory has issued a paper, U.S. Atomic Energy Commission Report BNWL-310, "An Evaluation of the Prospects for Large-Scale Production of Promethium-147." The report reviews the potential requirements and the estimated availability of Pm-147 as a recovered fission-product from spent nuclear fuels. The economic feasibility of producing additional Pm-147 by irradiation of Nd-146 is also evaluated.

The report may be obtained from National Bureau of Standards, CFSTI, U.S. Department of Commerce, Springfield, Va. 22151. The price of the document is $3.00.

PATENTS RESEARCH

The publication, *Quarterly Literature and Patent Reports on the Rare Earth Metals*, is available from Patents Research and Documentation, London, England. The reports list references to international literature, books, government publications and reports, and patents. The current subscription price is $200 a year.

The quarterly reports were begun in 1952 with report SL-1. Photostats of Nos. SL-1 to SL-14 (1956) are available for $20 each. Issues after SL-14 (Jan. 1956) are available at $45 each.

Subscriptions may be placed with Patents Research and Documentation, 12 Fulwood Place, High Holborn, London, W.C.1., ENGLAND.

R.E. COMPOUNDS CHART

RIC has just published two color charts showing the crystal structures of compounds of a rare-earth metal with one and with two non-rare earth elements.

The charts are presented as a modified periodic table. The representation helps visualize the relationship between the crystal structure type and the position of the non-rare earth elements in the periodic table.

The charts were compiled from published data available through January 31 of this year. They are available without charge from RIC.

NOTICE

IS-RIC-1, *Compilation of Rare Earth Products Available from Commercial Suppliers*, was mailed during the week of May 15. You should receive your copy in the next 30 days.

Yb Radiography

The uses and safety aspects of an Yb-169 source in a small exposure unit is reported by F. L. Green in the *Amer. Ind. Hygiene Ass. J.*, 444-448 (Sept. - Oct. 1966). The unit, weighing about 20 pounds, is useful in the radiography of castings, welds, and assemblies. Materials such as aluminum, magnesium, iron, wood and plastics are amenable to this technique.

Personnel protection is less difficult by the use of the low-energy source, which emits a 52-kev characteristic x-ray and various gamma rays with energies from 65 to 310 kev. Radiation scattered from air, the object and surrounding materials is less with Yb-169 than with conventional x-ray sources, or with other radio-sources such as Ir-192 or Co-60. An additional advantage over the conventional x-ray source is that electrical shock and explosion hazards are eliminated.

RENO GROUP

(Continued from Page 1)

application of field freezing for purifying cerium and yttrium alloys.

Development of analytical methods is under the direction of H. H. Heady, the assistance of K. G. Broadhead, K. R. Stever, and A. B. Whitehead. Radiotracer techniques are being used to monitor the electrotransport of certain impurities in rare-earth metals. The activation analysis of microconstituents and macroconstituents in rare-earth metals and electrolytes is being investigated, and atomic absorption is being used to determine non-rare-earth impurities in the electrowon metals.

EUROPIUM IN HUMANS

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respectively, based on whole body counting data obtained twice weekly over several months.

The study was reported in *Health Physics 12*, 1814 (1966).

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