Materials and Molecular Research

Newsletter

Lawrence Berkeley Laboratory
Berkeley, California

November 1979
Volume 3, No. 11

RESEARCH PROFILE

by CARSON JEFFRIES

SOMETHING NOVEL UNDER THE SUN!

An unusual state of matter known as "electron hole liquids" has been the object of continued investigation by my students, postdoctoral fellows and me for the past several years. These liquids, predicted to have superconducting and superfluid properties, exist at low temperatures inside certain semiconducting crystals. We have concentrated on one of these crystals, germanium, in our research. It was a fortunate selection since ultra-high purity Ge is grown at LBL by Hansen and Haller of Engineering and Technical Services.

General Description and History

Electron-hole liquids were discovered about 11 years ago in the USSR by Keldysh and Pokrovskii. They are produced by excitation by light (usually a laser pump) and have lifetimes on the order of microseconds. They are, in fact, a fundamental collective excited state of the crystal.

Light excites electrons from the valence band of Ge into the conduction band, leaving a hole. The electron and hole (electron-hole pair) quickly (10^{-9} sec) bind into a hydrogenic species, a quasiparticle termed an exciton. This gas of Mott-Wannier excitons or bosons (size ~150 Å) moves freely through the crystal.

With an increase in laser pump power they begin to interact. The great experimental surprise was that the exciton gas condensed into droplets (size 5 microns) of a dilute metallic (Fermi) liquid in a first-order phase transition, analogous to the water vapor-fog droplet (see Figure 1) instead of condensing into a dielectric liquid like H_2 as expected theoretically.

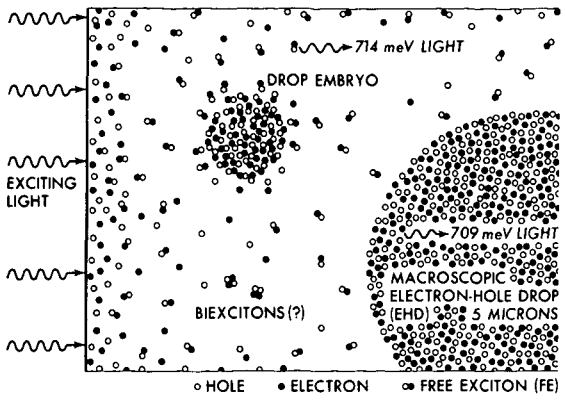

Fig. 1. Model of processes inside a Ge crystal leading to formation of electron-hole drops.

The electron hole droplets (EHD) contain equal numbers of electrons and holes (2×10^{17} cm^{-3}) which are free to move about and are no longer exciton-like. It is a quantum liquid, yet displays a number of classical properties.

Electron Hole Droplets (EHD)

The simplest experimental method used to explore the phenomena of electron-hole droplets is solid-state spectroscopy: the free excitons release recombination radiation

(Continued on page 4)

EDITORS CHOSEN FOR ANNUAL

The Scientific Editors for the 1979 MMRD Annual Report have been selected. The editors and their areas of responsibility follow:

A. BELL	Photochemical and radiation sciences; Chemical energy; Molecular thermodynamics.
C. B. MOORE	Chemical physics; Advanced isotope separation technology.
P. RICHARDS	Atomic physics; Solid state physics.
K. WESTMACOTT	Structure of materials.
D. WHITTLE	Mechanical properties; Physical properties; Solar energy.
H. HEINEMANN	Engineering materials; Coal research.
D. HESS	Chemical structures; High temperature and surface chemistry.
N. EDELSTEIN	Nuclear sciences.
P. ROSS	Energy storage; Industrial energy conservation.
L. DE JONGHE	Work for others.

ANNUAL REPORT SCHEDULING

Division Investigators are busily preparing their sections of the MMRD Annual Report. After initial clearances, the complete annual material must be submitted to the Scientific Editors no later than November 28.

Any questions about procedural matters in the Annual Report process may be addressed to CATHY WEBB, newly assigned Technical Editor in MMRD on assignment from TID. She may be reached at 5842, or messages may be left at 6062 for her response.

REVIEWERS FOR ANNUAL REVIEW CHOSEN!

The six invited reviewers for the 1980 Annual Review of the Materials and Molecular Research Division of the Laboratory have been announced. They are:

Professor Robert L. Coble, ceramist, MIT
Professor Morris E. Fine, metallurgist, Northwestern University
Professor Samuel Liu, physicist, Iowa State University
Professor John S. Waugh, physical chemist, MIT
Dr. Hartmut Wiedersich, materials scientist, ANL
Dr. John T. Yates, Jr., surface scientist, National Bureau of Standards.

STUDENT SERVICES

A complete typesetting service is now available on campus which focuses on preparation of resumes. The service is provided by the Undergraduate Business Association. For more information, stop by 398 Barrows Hall weekdays between 9AM and 3PM.

Free discussion sessions on the topic of preventive dentistry are held every Wednesday night at 8PM at the Berkeley Free Clinic, 2339 Durant Avenue. Participants learn about the structure of teeth, the process of tooth decay and gum disease, and how to prevent such problems. Some discussions will deal with how nutrition relates to good oral health. These sessions are open to the public.

Left to right: Prof. J. Pask, Prof. K. Okazaki, Prof. R. Bragg, Dr. I Ueda, Prof. M. Inagaki, Dr. Y. Imaoka, and Prof. A. Evans

FULRATH MEMORIAL AWARD SEMINAR WINNERS AND ORGANIZERS

The Second Annual Fulrath Memorial Award Symposium held in Hearst Mining Building on the University of California Campus October 18, 1979, featured a keynote address by Prof. Okazaki and awards were presented to Dr. I. Ueda, Prof. M. Inagaki, Dr. Y. Imaoka and Prof. Anthony Evans.

Prof. J. Pask and Chairman R. Bragg of the M.S.&M.E. Department at UCB welcomed the awardees and handled all arrangements for the Symposium.

BEST INTENTIONS OFT GO AWRY!

KENT MCARTHUR's fifth grade daughter is getting her first taste of chemistry in school this year.

One recent evening KENT found her laboring over a vocabulary list for the new subject with words like atom, molecule, compound, mixture, solution and experiment. MAGGIE invited her father to give her a hand, so he began reviewing her on the strange, new words. When they came to the word "investigation," she explained this was the term her class used for testing, experimenting, and confirming an idea.

Since we term our researchers here at the Laboratory , investigators, KENT quickly seized the opportunity to provide his daughter with a little insight about the activities at the place where he works.

"MAGGIE," he asked slyly, "what do you think the scientists at the Lawrence Berkeley Laboratory are called?"

Promptly, with all the assurance of a sharp ten year old, MAGGIE answered, "Alchemists!"

in the near IR at 714 meV, and the EHD at 709 meV, which are the key signatures of the two phases of the gas-liquid system. A definitive study, both experimental and theoretical, of the nucleation process was carried out by R. M. WESTERVELT (now at Harvard). He measured the surface tension of the droplets (10^{-5} that of water); he examined them in detail and explained a novel optical hysteresis effect. At a given excitation level the relative abundance of the two phases depends critically on the previous optical pumping history: the system has a memory! Droplets, formed by supersaturating the gas by a factor of ~4 to overcome surface tension, persist indefinitely, providing the crystal is continuously illuminated.

WESTERVELT devised a sensitive method to study motion of the droplets and found that at low excitation they essentially do not move (diffusion constant less than 10^{-9} cm^2 sec^{-1}), but are apparently bound to lattice impurities and are uncharged (to 1 in 10^6), or else are screened by a compensating cloud of carriers. (This result is in contradiction to earlier Soviet work).

One possible application of WESTERVELT's method would be construction of a solid state three-dimensional particle track detector similar to a cloud or bubble chamber. A large crystal of Ge could be uniformly optically excited just below threshold. An ionizing particle would produce sufficient electron-hole pairs to condense a string of tiny EHD along a path. These could be detected by stereo-video imaging of their recombination luminescence. Such a detector would be fast (10^{-5} sec), compact, and require operation at liquid helium temperature.

Electron-Hole Liquid (EHL)

R. S. MARKIEWICZ (now at General Electric), J. P. WOLFE (now at Urbana), and I discovered that small EHD can be forced to coalesce into a single large volume of electron-hole liquid (EHL) by creating a three-dimensional potential well of shear strain inside a crystal by special stress conditions. These large drops are photographed (Figure 2) with an IR scanning vidicon. Many phenomena can be studied for such strain-confined electron-hole liquids.

The EHL is, for plasma specialists, a cold, dense, compensated, multi-component, anisotropic plasma of constant density, i.e., a liquid, and as such it has some novel properties. J. E. FURNEAUX discovered magnetostriction: a large physical deformation both prolate and oblate with magnetic field. The compressibility was measured by S. M. KELSO (now at Bell Labs) and found to be 10^7 greater than water. FURNEAUX has also investigated magneto-oscillatory phenomena similar to

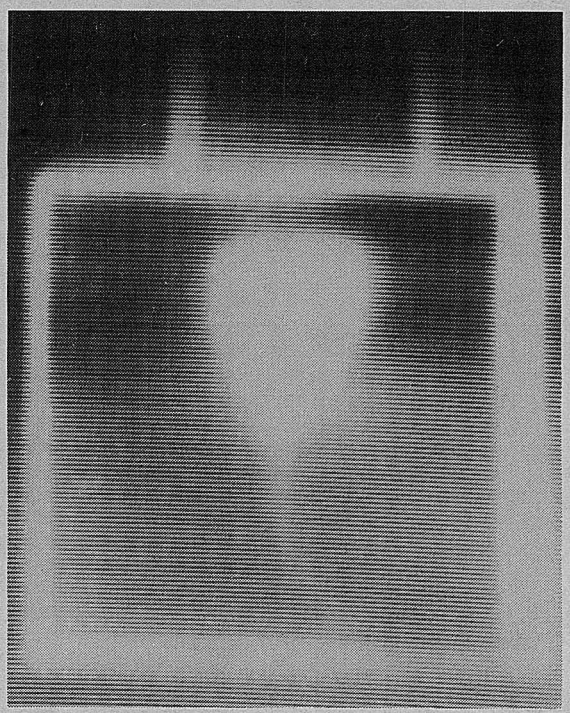

Fig. 2. Photograph of a large electron-hole drop in inhomogeneously strained Ge. The drop has the same shape as the strain well. Small droplets move into the strain well in a well-defined stream, pushed to the right by a phonon wind from the laser excitation.

that observed in other Fermi systems. In a magnetic field the EHL propagates Alfvén waves. We discovered dimensional standing wave resonances when the Alfvén wavelength matched the drop diameter: the drops act like tiny cavity resonators. The remarkable change in density and lifetime with stress is now understood. Less understood are numerous plasma-type instabilities.

Point Focused Laser Effects

In unstressed Ge excited by a point focused laser, J. P. WOLFE found that droplets are blown rapidly into an anisotropic cloud, a few millimeters in size, due to the flux of non-equilibrium phonons, the so-called "phonon wind" effect. Drops are also exceedingly sensitive to small strain gradients and can be accelerated to the speed of sound where shock wave heating causes them to evaporate.

New Exciton Experiments

The work on droplets has revived interest in much more sophisticated experiments on the simple free exciton itself. J. C. CULBERTSON, using spatial imaging techniques, is studying the detailed motion (diffusion? hopping? trapping? surface capture?) and lifetime of free excitons. There is as yet no adequate theoretical explanation of the lifetime which depends on crystal size and dislocation concentration.

The existence of simple molecular complexes such as free bi-excitons, tri-excitons, etc., has not yet been experimentally verified in Ge, although free bi-excitons in Si have been observed.

The study of molecular complexes of electrons and holes in semiconductors is analogous to the study of ordinary chemical molecules from simple to complex, except that the medium is the crystal lattice which, although ultra-pure, is not as pure as a vacuum. In short, the molecules get stuck on impurities and there is increasing data on bound multi-exciton complexes. J. M. PEREZ is developing a spectrometer with a sensitivity several orders greater than previously used, to help unravel the present mysteries about free and bound excitonic molecules. Another very sensitive method, microwave paramagnetic resonance, is being used by E. J. PAKULIS to examine the effect on donor resonant signals of trapped exciton(s) and droplets.

Varied Future Directions

Electron-hole liquids have been observed with a varying degree of veracity in Ge, Si, GaP, CdSe, CdS, ZnO, GaA, and other semiconductors--some with high critical temperatures (100°K). There is some evidence for two-dimensional liquids in layered structures.

Generally, the experimental discoveries have preceded theoretical predictions. The field is open--there are questions on a number of related excited states in crystals: Can the classical Mott metal-insulator transition be observed in Ge? Will excitons exhibit a Bose condensation as originally theorized? Will high temperature metallic electron-hole liquids be found? Is there a two-dimensional liquid surface state? These interesting questions are being pursued and will require sophisticated experiments for definitive answers.

Conclusion

The longer range applications for this basic research are probably unforseeable since applications have a way of springing up at what appear to be tangents to the primary course of development. Yet, sometimes, these tangents often become more important than anticipated.

Futurists see possibilities arising from the data on confining and using these low temperature plasmas that may provide valuable insight to fusion energy researchers who are

struggling to contain high temperature plasmas.

In data collection, storage, and recall, the optical memory exhibited by these crystals suggests the possibility of high speed optical storage and recall using light as the activation agent. Perhaps anticipated superconductivity and superfluidity will be observed and give new impetus to efficient storage and transmission of energy without the heavy energy drains which now accompany conventional technology.

Basic research is a science of beginnings--nature reveals itself in new and unexpected ways allowing expansion and growth in many directions. Almost all of our present major technologies are unexpected fallouts from earlier basic research. Being curious about a novel state of matter, and investigating it in detail with no attempt to bias the investigation toward preconceived practical ends, is one of the best ways to discover an inconceivable practical idea!

BRAD MOORE REPORTS ON TRIP TO CHINA & JAPAN

C. BRADLEY MOORE recently returned from a four-month trip to Japan and mainland China where he participated in conferences and discussions with local scientists and presented several lectures on laser-induced chemistry, multiphoton dissociation, and laser isotope separation.

BRAD visited widely at research institutions and universities in both countries.

Some highlights and observations:

The overall level of laser development in China is substantially behind that of the West. Nevertheless, they are beginning to produce useful lasers of standard types and research is progressing rapidly.

Research on laser-induced chemical reactions and surface reactions was quite evident with considerable interest directed toward catalysis. Some of the ideas for use of lasers initiated at Fudan and Kirin Universities are quite advanced and represent an important area of research where Chinese scientists may well make some of the most important contributions in the near future.

In Japan there was much excellent chemical research conducted with lasers. In particular, the Institute of Molecular Science (IMS) points up the Japanese government's determination to advance molecular sciences, especially those related to energy. This Institute, less than two years old, has equipment and facilities comparable to the best Max-Planck Institutes and superior to fundamental research laboratories in the United States.

Novel and outstanding research at IMS includes laser-induced processes on surfaces, electrochemical solar energy conversion, high-resolution spectroscopy, picosecond spectroscopy, and molecular calculations.

Although university research funding in Japan has been increasing, the facilities are generally not yet comparable with those at major U.S. universities.

MITCHEL SHEN MEMORIAL FUND

A Memorial Fund has been established in the name of MITCHEL SHEN, recently deceased UC Professor of Chemistry and Investigator with MMRD, to provide financial aid to foreign students.

The fund, known as the MITCHEL SHEN MEMORIAL FUND, was established by the College of Chemistry. Donations may be sent to the Chemical Engineering Department, University of California, Berkeley, CA 94720.

PEOPLE NEWS

MARY NORTON, secretary for Profs. CLARKE and RICHARDS, resigned on October 23 in order to care for a new baby girl. MARY and her husband have been waiting nearly three years to adopt a child so you can imagine her excitement when she learned on Thursday, October 18 that they would receive their little girl, Heather, the following Wednesday.

Support staff, other secretaries, students and professors attended a surprise going away party and baby shower held in LeConte on the 23rd.

Congratulations, MARY--our love and best wishes go with you!

♦

Prof. GARETH THOMAS, MMRD Investigator and UCB Professor of Metallurgy, was a guest of the USSR Academy of Sciences October 12-19. GARETH presented the keynote lecture at the 11th AU-Soviet Congress on Electron Microscopy in Tallinn, USSR, October 18.

♦

Prof. GLENN SEABORG presented "Our Heritage of the Elements" on November 13 in Chicago as the Distinguished Lecture in Materials & Society for 1979.

The Distinguished Lectureship is jointly sponsored by the American Society for Metals (ASM) and The Metallurgical Society of AIME. Established in 1971, the purpose of the Lectureship is to clarify the role of materials engineering in technology and in society in its broadest sense, to present an evaluation of progress made in developing new technology for the ever-changing needs of technology and society, and to define new frontiers for materials engineering.

♦

Dr. CARL LAMPERT has finished his Ph.D. studies with a thesis on the "Chemical Structural and Optical Characterization of a Black Chrome Solar Selective Absorber."

CAROL HACKER was the guest of honor of a baby shower and potluck buffet October 30 at noon in Latimer Hall on Campus.

CAROL, who will be going on maternity leave December 1, was feted and showered by a large, warm group of MMRD and Campus personnel with whom she has worked during her years on the Campus. It was a happy time for all.

♦

MEHMET SARIKAYA, graduate student with THOMAS's Group, took third-in-class honors in Transmission Electron Microscopy, Class 4, of the 1979 Metallographic Exhibit jointly sponsored by ASM and the International Metallographic Society.

MEHMET's exhibit was on display at the ASM Materials and Processing Show and Congress in Chicago, November 13-15.

Congratulations, MEHMET.

♦

Prof. DONALD R. OLANDER has been appointed Chairperson of the Department of Nuclear Engineering at UCB.

Since DON is on sabbatical leave in France, Prof. Selig Kaplan will fill in as Acting Chairperson until DON returns next year.

♦

Prof. DAVID P. WHITTLE attended an international conference on "Behavior of High Temperature Alloys in Aggressive Environments" from October 15-18. DAVID served as Rapporteur for the round table discussions; he summarized the highlights of the various conference sessions and stimulated the discussions. In addition, he will act as Editor for the proceedings.

The conference was jointly sponsored by the OK Metals Society, the Dutch Bond Voor Materialenkennis, and the Commission of European Communities Joint Research Centre.

Prof. HOWARD SHUGART presented a slide show entitled "Cultural Aspects of a Sabbatical" for brown-baggers at lunch November 13 in the auditorium of Building 62. SHUGART's presentation featured Turkey, Saudi Arabia, and Nigeria and was liberally sprinkled with anecdotes and sidelights about the countries and their people. Very, very interesting, HOWARD. Thanks!

♦

Prof. KENNETH RAYMOND, and his research assistant, FRED WEITL, were recently written up in Science News, a semi-popular weekly magazine devoted to science reporting, for their work on plutonium poisoning. They have designed a compound which is as effective as the drugs currently used in treating plutonium poisoning (DTPA and ferrioxamine B) at one-tenth the concentration. At even lower concentrations the compounds are essentially non-toxic!

♦

The Marine Biomedical Institute for Distinguished Scholars at the University of Texas has named Prof. GLENN SEABORG a Visiting Green Scholar. On November 12, SEABORG presented a lecture at the Galveston Medical Branch of the Institute titled "Reminiscences on the Development of Some Medically Useful Radionuclides."

J. W. MORRIS, Jr. will be the Chairperson of the 4th International Cryogenics Materials Conference scheduled for 1981.

♦

GLEN BAUM is away on a vacation trip to New Zealand!

♦

MARIA ISABEL PEREZ, graduate student with KEN WESTMACOTT, recently gained membership in the Golden Gate Chapter of the American Society for Metals. Congratulations, MARIA.

♦

Dr. DONALD BOON of the AL LEVY Group, will be making a presentation on "Advanced Electron Beam Techniques for Metallic and Ceramic Protective Coating Systems" at the Conference on Specialized Cleaning, Finishing and Coating Processes on February 6th in Los Angeles. The Conference is jointly sponsored by ASM and the Society for the Advancement of Material and Process Engineering.

♦

GLENN SEABORG, Nobel Laureate, MMRD researcher and LBL Associate Director and University Professor of Chemistry, UCB, spoke October 24 in Pasadena at the California Institute of Technology. The address, entitled "The New Elements," was part of the Nobel Laureate Series sponsored by the J. T. Baker Chemical Co.

LBL REPORTS BY MMRD PERSONNEL

To obtain a copy of any of the LBL/MMRD reports listed below, write directly to the writer whose name is underlined, c/o the Editors, MMRD Newsletter, Bldg. 62, Rm. 209, Lawrence Berkeley Laboratory, Berkeley, CA 94720. If several reports are requested, and the underlined names are different — separate requests are necessary. Nothing more than a postcard is needed, and if several are ordered at one time, use 3 × 5 cards in one envelope.

LBL-8462: The Effect of Austenitizing Temperature Upon the Microstructure and Mechanical Properties of Experimental Fe/Cr/C Steels ... *M. F. Carlson, B. V. Narasimha Rao, and G. Thomas*

LBL-8501: An Investigation of the Effects of Particle Size on the Mechanical Properties of Porous and Tin Infiltrated Niobium Rods Fabricated by a Thermoplastic-Powder Metallurgy Technique ... *Abid Noman* (M. S. Thesis) (*M. Pickus*)

LBL-8565: Fourier Transform Multiple Quantum NMR ... G. Drobny, A. Pines, S. Sinton, D. Weitekamp, and D. Wemmer

LBL-8652: Vibrational Dephasing of Polyatomic Molecules in Condensed Phases. II. Temperature Dependence of Raman Spectral Lines Resulting From Energy Exchange in 1,2,4,5-Tetramethylbenzene ... P. A. Cornelius, R. M. Shelby and C. B. Harris

LBL-9008: The Mechanism of Ionization Damage in Glassy Ceramics ... J. Y. Laval and K. H. Westmacott

LBL-9471: Chemisorption and Reactivity Studies of Small Molecules on Rhodium Surfaces ... D. G. Castner (Ph.D. Thesis) (D. A. Shirley)

LBL-9535: Metallurgical Factors Controlling Impact Properties of Two Phase Steels ... J. Y. Koo and G. Thomas

LBL-9553: Electrons on the Surface of Liquid Helium ... D. K. Lambert (Ph.D. Thesis) (P. Richards)

LBL-9693: A Quasi-Relativistic SCF X-α Study of Octahedral $5f^1$ Complexes ... G. Thornton, N. Rösch and N. Edelstein

LBL-9737: Grain Boundary Precipitation in Aluminum Alloys: Effect of Boundary Structure ... R. Gronsky and P. Furrer

LBL-9790: An Angle-Resolved Photoemission Determination of The Band-Structure of Platinum Between Γ and X ... G. Thornton, R. F. Davis, K. A. Mills, and D. A. Shirley

LBL-9793: Transient Annealing of GaAs By Electron and Laser Beams ... I. Golecki, M.-A. Nicolet, J. L. Tandon, P. M. Asbeck, D. K. Sadana, and J. Washburn

LBL-9797: Development of A-15 (V_3Ga) Superconducting Material Through Controlled Precipitation ... M. Hong, D. Dietderich and J. W. Morris, Jr.

LBL-9801: Hydrogen Reduction of Cobalt Ferrite ... J. R. Porter and L. C. De Jonghe

LBL-9802: Microstructure, Defects, and Sodium Transport in Sodium Beta-Alumina Solid Electrolytes ... L. C. De Jonghe

LBL-9804: Pulsed Electron Beam Induced Recrystallization and Damage in GaAs ... J. L. Tandon, I. Golecki, M-A. Nicolet, D. K. Sadana, and J. Washburn

LBL-9843: The Spectrum of the Microwave Background ... P. L. Richards and D. P. Woody

LBL-9856: Electron Microscope Studies of Ion Implanted Silicon and Gallium Arsenide After Subsequent Laser and Furnace Annealing ... D. K. Sadana, M. C. Wilson, and G. R. Booker (J. Washburn)

LBL-9862: Temporal Behavior of NO_3 and N_2O_5 in the Stratosphere ... P. S. Connell and S. Solomon (H. Johnston)

LBL-9865: L_3-Edge Anomalous Scattering of X-Rays by Praseodymium and Samarium ... L. K. Templeton, D. H. Templeton and R. P. Phizackerley

LBL-9869: Correlation of Cyclohexene Reactions on Platinum Crystal Surfaces over 10-Orders of Magnitude Pressure Range: Variations of Structure Sensitivity, Rates, and Reaction Probabilities ... S. M. Davis and G. A. Somorjai

LBL-9880: Anomalous Scattering of X-Rays by Cesium and Cobalt Measured with Synchrotron Radiation ... D. H. Templeton and L. K. Templeton

LBL-9893: All-Nb Low Noise dc SQUID with 1μm Tunnel Junctions ... R. F. Voss, R. B. Laibowitz, S. I. Raider, and J. Clarke

CALENDAR

November 30: Surface Science & Catalysis Seminar: Dr. A. G. Oblad, University of Utah (SPECIAL SEMINAR) "Catalytic Steam Reforming of Aromatics" 1:00 pm Bldg 62, Rm 203, LBL/MMRD

November 30: Mech. Eng. Technical Meeting: L. Kanstein "Cancer Treatment Program at the 184-In. Cyclotron" 8:30 am Bldg. 90 Conference Room, LBL

December 5: Surface Science & Catalysis Seminar: R. Chianelli, Exxon Research & Dev. Co. "Structure & Properties of Molybdenum Sulfide Catalytic Materials" 4:00 pm Bldg 62, Rm 203, LBL/MMRD

December 14: Mech. Eng. Technical Meeting: E. Hoyer "A Unique Operational Solar Hot Water System" 8:30 am Bldg 90 Conference Room, LBL

December 24-25: CHRISTMAS HOLIDAY

December 26-28: LBL Shutdown--Time off charged to vacation or leave w/o pay

December 31: NEW YEAR's HOLIDAY

January 1: 1980 NEW YEAR'S HOLIDAY

January 3-8: 1980 AAAS Meeting. San Francisco, CA

February 11-12: 1980 MMRD Annual Review Meetings, Bldg 62, LBL

SECOND CLASS MAIL

MATERIALS AND MOLECULAR RESEARCH DIVISION
David Shirley, Head
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

MMRD NEWSLETTER
Editor: Cathy Webb
Writer/Editor: Roy McCollough
Bldg. 62, Rm. 209
Phone (415) 486-6062
486-5842
FTS 451-6062

PUB-284 11-79/800 Prepared for U.S. Department of Energy under Contract W-7405-ENG-48