

052
H 638
V. 1
(2)

7963369
5

High-Pressure Science and Technology

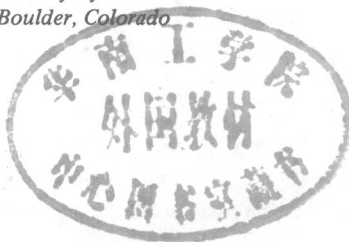
Sixth AIRAPT Conference

Volume 1 Physical Properties and Material Synthesis

Edited by

K. D. Timmerhaus and M. S. Barber

*University of Colorado
Boulder, Colorado*



PLENUM PRESS • NEW YORK AND LONDON

Library of Congress Cataloging in Publication Data

International Conference on High Pressure, 6th, University of Colorado, 1977.
High-pressure science and technology.

Includes index.

CONTENTS: v. 1. Physical properties and material synthesis – v. 2. Applications and mechanical properties.

I. High pressure (Technology) – Congresses. I. Timmerhaus, Klaus D. II. Barber, M. S. III. International Association for the Advancement of High Pressure Science and Technology. IV. Title.

TP 156.P75157

660.2'8429

78-21888

ISBN 0-306-40066-9

Proceedings of the Sixth AIRAPT International High Pressure Conference
held at Boulder, Colorado, July 25–29, 1977

© 1979 Plenum Press, New York
A Division of Plenum Publishing Corporation
227 West 17th Street, New York, N.Y. 10011

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted,
in any form or by any means, electronic, mechanical, photocopying, microfilming,
recording, or otherwise, without written permission from the Publisher

Printed in the United States of America

High-Pressure Science and Technology

Sixth AIRAPT Conference

**Volume 1
Physical Properties and
Material Synthesis**

HIGH-PRESSURE SCIENCE AND TECHNOLOGY
Sixth AIRAPT Conference

- Volume 1 Physical Properties and Material Synthesis**
- Volume 2 Applications and Mechanical Properties**

PREFACE

High pressure has become a basic variable in many areas of science and engineering. It extends from disciplines of geophysics and astrophysics through chemistry and physics to those of modern biology, electrical and chemical engineering. This breadth has been recognized for some time, but it was not until the early 1960's that an international group of scientists and engineers established the Association Internationale for Research and Advancement of High Pressure Science and Technology (AIRAPT) for bringing these various aspects of high pressure together at an international conference. The First AIRAPT International High Pressure Conference was held in 1965 in France and has been convened at approximately two to three-year intervals since that time. The past four AIRAPT International High Pressure Conferences have been held in Germany, Scotland, Japan and the U.S.S.R.

Since the first meeting of this kind, our understanding of high pressure behavior of physical systems has increased greatly. Applied research, which is coupled to the expansion of our basic knowledge, has led to the emergence of technologies dependent upon the high pressure properties of materials that have evolved over the past decade or two. In the early 1960's explosive forming, welding, and compaction were rather poorly understood and had limited applications. Today, an expanding variety of products are made possible through this technique. The AIRAPT International High Pressure Conferences have proved to be one of the more effective means of bringing scientists and engineers from many countries together for exchanging new ideas and disseminating new knowledge concerning the properties of materials at high pressures. By contributing to the efficient exchange of new information on high pressure applications and techniques, the AIRAPT International High Pressure Conferences have played an important part in the rapid advances that have occurred in the past two decades, both in our basic understanding of high pressure behavior and in the applied research that has followed.

The Sixth AIRAPT International High Pressure Conference was organized by the University of Colorado and the Association Inter-

ationale for Research and Advancement of High Pressure Science and Technology. The conference was held in Boulder, Colorado, July 25 to 29, 1977 and was attended by approximately 500 participants from 24 nations. This technical meeting was sponsored by AIRAPT, The International Union of Pure and Applied Chemistry (IUPAC), the American Institute of Chemical Engineers (AIChE), and the University of Colorado. Gracious support for the conference was provided by the U.S. National Science Foundation, the U.S. Office of Naval Research, the U.S. Department of the Army, the U.S. Air Force Office of Scientific Research, and the U.S. Department of Energy.

The conference was opened with brief introductory and welcoming remarks by University of Colorado Chancellor J. R. Nelson, Dr. K. D. Timmerhaus, chairman of the Conference Planning Committee, and R. N. Keeler, the U.S. member of the AIRAPT Executive Committee. Reminiscences of the late P. W. Bridgman were presented by his daughter, Mrs. Jane Bridgman Koopman, and the first P. W. Bridgman Award Medal was presented by Dr. H. Ll. D. Pugh, president of AIRAPT, to Dr. Harry G. Drickamer of the University of Illinois.

The P. W. Bridgman Award Lecture by Dr. Drickamer pointed up the dual applications of high pressure research in increasing understanding of the behavior and states of matter at high pressure and of the effects of pressure on electronic states and chemical properties of matter. He noted that the basic effect of pressure is to decrease the interatomic distance and thus to increase the overlap between adjacent electronic orbitals. As a consequence, the energy of any one electronic state, in general, changes with respect to that of other states. The information which can be extracted from these energy shifts can conveniently be classified in three categories. (1) It is possible to characterize electronic energy states, electronic excitations, and molecular conformations. (2) It is possible to perform critical tests of theories and hypotheses concerning electronic processes. (3) In a wide variety of materials the relative shift in energy is sufficient to establish a new ground state for the system (or to modify its characteristics greatly by configuration interaction). These new ground states may have new and interesting physical and chemical properties. Studies of pressure-induced electronic transitions have contributed considerably to our understanding of electronic phenomena.

In keeping with the role of AIRAPT, the conference dealt with the full spectrum of high pressure investigations. Because these were so diverse, the Conference Planning Committee was organized along ten main divisions. These divisions and the group of individuals responsible for these divisions are given below.

- I. High Pressure Applied to Physical Systems - C. A. Swenson
- II. High Pressure Phase Equilibria and Separation Processes - C. A. Eckert

- III. High Pressure Kinetics - W. J. le Noble
- IV. Metrology and Instrumentation at High Pressures -
P. L. M. Heydeman and D. R. Lide
- V. Material Synthesis Under Pressure - F. P. Bundy
- VI. High Pressure Geophysical/Geological Applications -
T. J. Ahrens, A. J. Boettcher and G. C. Kennedy
- VII. High Pressure in Energy Resource Recovery - A. S. Kusubov
and M. L. Wilkins
- VIII. Mechanical Properties at High Pressures - A. L. Ruoff
- IX. Industrial Applications of High Pressure - C. B. Boyer
- X. Future Directions in High Pressure Applications -
R. N. Keeler

Certainly the success of the Sixth AIRAPT International High Pressure Conference was in many ways due to the excellent work of this group of individuals and those who assisted them.

The International Advisory Committee also contributed significantly to the success of the conference by alerting the Conference Planning Committee to new work in high pressures as well as supplying names of younger researchers whose presence at the conference was to be encouraged.

Many other individuals helped in the organization and execution of this conference. Special thanks are due to H. Spetzler and L. M. Christiansen responsible for the local arrangements, Mrs. K. D. Timmerhaus and Mrs. H. Spetzler, cohosts for the spouses activities, and Mrs. E. R. Dillman, Mrs. L. M. Dimond, Mrs. B. Wassan, Mrs. M. L. Woolard and J. D. Smith for their assistance with completion of the program copy.

Finally, the chairman wishes to express his appreciation to the Session Chairmen and to the individuals who reviewed the many manuscripts prior to publication in these Proceedings. These two volumes attempt to present a flavor of the presentations and discussions which highlighted this successful conference.

K. D. Timmerhaus

SPECIAL ACKNOWLEDGMENT

The editors take great pleasure in recognizing the outstanding assistance of many individuals in publishing these Proceedings. Special thanks are due to Mrs. Lenore Dimond, Mrs. Elva Dillman, Mrs. Ruby Fulk, and Mrs. Julie Welker for preparing and compiling the typescript, and to Steve Dyer of Plenum Press for advising and for production.

K. D. Timmerhaus
M. S. Barber

P. W. BRIDGMAN AWARD

Dr. Harry G. Drickamer, Professor of Chemical Engineering and Physical Chemistry at the University of Illinois, is the recipient of the first P. W. Bridgman Award presented by the Association Internationale for the Advancement of High Pressure Science and Technology (AIRAPT). The award is named for the late Nobel laureate, P. W. Bridgman, and was presented to the recipient on July 25, 1977 at the 6th AIRAPT International High Pressure Conference held at the University of Colorado in Boulder, Colorado.



Presentation of the P. W. Bridgman Medal to Dr. H. G. Drickamer (right) by Mrs. Jane Bridgman Koopman, daughter of Nobel laureate P. W. Bridgman, and Dr. H. L. D. Pugh, President of AIRAPT.

The fundamental thesis of Professor Drickamer's research program is that very high pressure is a most powerful, indeed an essential, variable for understanding electronic structure and electronic behavior in condensed systems. The central feature of his research has been his selection of those classes of materials and types of measurements which yield the most important information and most useful generalizations about electronic phenomena. Incidental to this process has been the development of techniques for measuring various features of optical absorption and emission spectra and of Mössbauer resonance spectra as well as electrical resistance to relatively high pressures, in some cases to several hundred kilobars.

An overview of one aspect of Professor Drickamer's extensive research program is given in his P. W. Bridgman Award lecture which is published as the first paper in this volume.

6th AIRAPT CONFERENCE PLANNING COMMITTEE

K. D. Timmerhaus, University of Colorado, Chairman
T. J. Ahrens, California Institute of Technology
A. J. Boettcher, University of California, Los Angeles
C. B. Boyer, Battelle Columbus Laboratory
F. P. Bundy, General Electric Company
C. A. Eckert, University of Illinois
P. L. M. Heydemann, National Bureau of Standards
R. N. Keeler, Lawrence Livermore Laboratory
G. C. Kennedy, University of California, Los Angeles
A. S. Kusubov, Lawrence Livermore Laboratory
W. J. le Noble, State University of New York, Stony Brook
D. R. Lide, National Bureau of Standards
A. L. Ruoff, Cornell University
C. A. Swenson, Iowa State University
M. L. Wilkins, Lawrence Livermore Laboratory

INTERNATIONAL ADVISORY COMMITTEE

O. Anderson, University of California, Los Angeles, U.S.A.
D. Bloch, Laboratoire de Magnétisme, France
H. G. Drickamer, University of Illinois, U.S.A.
E. U. Franck, Technische Hochschule Karlsruhe, W. Germany
D. Francois, Commissariat à l'Energie Atomique, France
S. Hamann, Chemical Research Laboratories, Australia
R. N. Keeler, Lawrence Livermore Laboratory, U.S.A.
H. Larker, ASEA, Sweden
J. Osugi, Kyoto University, Japan
H. L. D. Pugh, Rolls Royce Ltd., England
S. Saito, Tokyo Institute of Technology, Japan
J. E. Schirber, Sandia Laboratories, U.S.A.
K.-F. Seifert, Universität Bonn, W. Germany
I. Sorgato, Università di Padova, Italy
N. J. Trappeniers, Van der Waals Laboratorium, The Netherlands
L. F. Vereschagin, Institute for High Pressure Physics, U.S.S.R.
(Deceased February 20, 1977)
B. Vodar, LIMHP, CNRS, France
K. E. Weale, Imperial College of Science and Technology, England
B. Whalley, National Research Council of Canada, Canada

CORRESPONDING MEMBERS OF ADVISORY COMMITTEE

B. Baranowski, Polish Academy of Sciences, Poland
B. Buras, Danish Atomic Energy Commission, Denmark
J. B. Clark, National Physical Research Laboratory, South Africa
K. A. H. Heremans, Katholieke Universiteit Leuven, Belgium
V. P. J. Meisalo, University of Helsinki, Finland
V. S. Nanda, University of Delhi, India

CORRESPONDING MEMBERS OF ADVISORY COMMITTEE (CONTINUED)

J. L. Olsen, Eidgenössische Technische Hochschule Zürich,
Switzerland
F. E. Prieto, Instituto de Física, México
V. N. Shanov, Institute of Chemistry and Technology, Bulgaria

ACKNOWLEDGMENTS

The Conference Planning Committee is deeply appreciative for the support given by the following organizations to the 6th AIRAPT International High Pressure Conference.

SPONSORS

Association Internationale for Research and Advancement of High
Pressure Science and Technology (AIRAPT)
The International Union of Pure and Applied Chemistry (IUPAC)
The American Institute of Chemical Engineers (AIChE)
The University of Colorado

SUPPORTERS

U.S. Air Force Office of Scientific Research (AFOSR)
U.S. Department of Energy (DOE)
U.S. Department of the Army (DOA)
U.S. Office of Naval Research (ONR)
U.S. National Science Foundation (NSF)

COHOSTS

American Instrument Company, Industrial Products Division
ASEA
Autoclave Engineers, Inc.
Harwood Engineering Company, Inc.
National Forge Company
Pressure Products Industries, Division of the DURIRON
Company, Inc.
Speciality Engineering Associates
The University of Colorado

7963369

5



E7953369

CONTENTS OF VOLUME 1



Preface	xix
P. W. Bridgman Award	xxiii
6th AIRAPT Conference Planning Committee	xxv
International Advisory Committee	xxv
Corresponding Members of International Advisory Committee ..	xxvi
Acknowledgments	xxvi

P. W. BRIDGMAN AWARD LECTURE

0-0 High Pressure Studies of Electronic Phenomena, H. G. DRICKAMER, University of Illinois	1
---	---

I. HIGH PRESSURE APPLIED TO PHYSICAL SYSTEMS

A. Equations of State of Solids

A-1 Status of Equation of State of Solids, A. L. RUOFF, Cornell University, and L. C. CHHABILDAS, Sandia Laboratories	19
A-2 Metallic High Pressure Equation-of-State Derived from Experimental Data, R. GROVER, Lawrence Livermore Laboratory, University of California	33
A-3 Generalized Hugoniot and 0°K Curves of Elements, V. F. ANISICHKIN, Institute of Hydrodynamics, Siberian Division of the USSR Academy of Sciences	42
A-4 A Universal Equation of State for Fluids and Solids at Shock Pressures, F. E. PRIETO, Instituto Nacional de Energia Nuclear, México, and C. RENERO, Universi- dad Nacional de México	50
A-5 Isothermal Compression of V, Nb, and Ta to 100 kbar: Correlation with Ultrasonic, Shock Wave, and Other Static Data, L-C. MING and M. H. MANGHNANI, University of Hawaii	54
A-6 Shock Compression of Lead Fluoride at Room Tempera- ture, D. P. DANDEKAR and R. M. LAMOTHE, U.S. Army Materials and Mechanics Research Center Watertown	63

A-7	Response of Porous Beryllium to Static and Dynamic Loading, W. M. ISBELL, Effects Technology, Inc., and O. R. WALTON and F. H. REE, Lawrence Livermore Laboratory, University of California	68
A-8	Determination of the Grüneisen γ for Beryllium at 1.2 to 1.9 Times Standard Density, T. NEAL, Los Alamos Scientific Laboratory, University of California	80
A-9	High-Pressure Multiple-Shock Response of Aluminum, R. J. LAWRENCE and J. R. ASAY, Sandia Laboratories ...	88
A-10	Volume Dependence of the Grüneisen Coefficient for Aluminum, J. P. ROMAIN, A MIGAULT and J. JACKQUESSON, Université de Poitiers, Poitiers Cédex	99
A-11	Pressure Effect on Compressibility of Aluminum Single Crystals from -196 to 25°C, N. J. TRAPPENIERS, P. VAN'T KLOOSTER and S. N. BISWAS, Universiteit van Amsterdam	108

B. Phase Transitions in Solids

B-1	Study of Phase Transitions at High Pressure, A. JAYARAMAN, Bell Laboratories	114
B-2	Studies of Electron Transitions Using Solid He Pressure Techniques, J. E. SCHIRBER, Sandia Laboratories	130
B-3	High Pressure Phonon Dispersion of Zinc Chalcogenides and the Metallic Transition, B. A. WEINSTEIN, Purdue University	141
B-4	The Pressure Induced Strain Transition in NiF_2 , J. D. JORGENSEN and T. G. WORLTON, Argonne National Laboratory, and J. C. JAMIESON, The University of Chicago	152
B-5	Studies of the High Pressure Transition in Sulfur, A. L. RUOFF and M. C. GUPTA, Cornell University	161
B-6	Behavior and Properties of Sulfur at Pressures of 300 kbar and Higher, K. J. DUNN and F. P. BUNDY, General Electric Company	172
B-7	Some Applications of High Pressure Studies of Phase Transitions in Solids, G. A. SAMARA, Sandia Laboratories	177
B-8	Stress Effects in Ferroelectric Ceramics, I. J. FRITZ and J. D. KECK, Sandia Laboratories	194

B-9	Electrical Response of Shock-Wave-Compressed Ferro-electrics, P. C. LYSNE, Sandia Laboratories	202
B-10	Theoretical Basis for Understanding the Mixed Phase Region in Shock-Compressed Iron, J. W. FORBES, Naval Weapons Center, and G. E. DUVAL, Washington State University	210
B-11	A New Allotropic Phase of Cerium Above 122 kbar, S. ENDO and J. FUJIOKA, Osaka University, and H. SASAKI, Hokkaido University	217
B-12	Lattice Parameters and Volume Compressibility of Ytterbium up to 300 kbar, K. SYASSEN and W. B. HOLZAPFEL, Max-Planck-Institut Für Festkörperforschung	223
B-13	Electrical Characterization of Pressure-Induced Phase Transitions, B. A. LOMBOS, H. M. MAHDALY and B. C. PANT, Concordia University	227
C. Phase Diagrams		
C-1	Preparation of Metallic Hydrides by High Pressure Gaseous Hydrogen, B. BARANOWSKI, Institute of Physical Chemistry, Polish Academy of Sciences	238
C-2	High Pressure Studies of Palladium Alloy/Hydrogen Systems, B. BARANOWSKI, Institute of Physical Chemistry, Polish Academy of Sciences, and F. A. LEWIS, Queen's University	241
C-3	<u>In Situ</u> Measurements of Changes of Ferromagnetism Caused by High Pressure Gaseous Hydrogen, H. J. BAUER, University of Munich, and B. BARANOWSKI, Institute of Physical Chemistry, Polish Academy of Sciences	248
C-4	Phase Relations in the In-Bi Binary System to 40 kbar, E. RAPOPORT, Soreq Nuclear Research Centre, and P. W. RICHTER and J. B. CLARK, National Physical Research Laboratory	253
C-5	High Pressure Phase Relations for KDP-Type Compounds, E. RAPOPORT, Soreq Nuclear Research Centre, and J. B. CLARK and P. W. RICHTER, National Physical Research Laboratory	261
C-6	Phase Transition of InSb, B. OKAI and J. YOSHIMOTO, National Institute for Researches in Inorganic Materials	266
C-7	Phase Transitions in Intermetallic Compounds under Pressure: Synthesis of Tungsten Germanides, S. V. POPOVA and L. N. FOMITCHEVA, Institute of High Pressure Physics	272

C-8	Phase Transitions in Group III-V and II-VI Semiconductors at High Pressure, S. C. YU, C. Y. LIU and I. L. SPAIN, University of Maryland, and E. F. SKELTON, Naval Research Laboratory	274
C-9	On Gallium in the Alpha and Delta Plutonium Lattice, R. B. FISCHER, Rockwell International, Atomics International Division	287

D. Low Temperature Phenomena

D-1	Neutron Scattering at 4.5 GPa and 20 K, D. B. McWHAN, Bell Laboratories	292
D-2	The Synthesis of Al ₅ -Type Materials at High Pressures: Comments and Critiques, A. W. WEBB, T. L. FRANCAVILLA and R. A. MEUSSNER, Naval Research Laboratory, and R. M. WATERSTRAT, National Bureau of Standards	297
D-3	Superconductivity at High Pressure, T. F. SMITH, Monash University	309
D-4	Anomalous Pressure Dependence of the Superconducting Transition Temperature of Dilute Alloys of LaSn ₃ Containing Light Rare Earth Impurities, L. E. DeLONG and M. B. MAPLE, University of California at San Diego	320
D-5	Indications for a Phase Transition in Cerium Near 160 kbar, C. PROBST and J. WITTIG, Institut für Festkörperforschung	329
D-6	Static Crystal Field for Orthohydrogen Impurities in Parahydrogen, J. C. RAICH and L. B. KANNEY, Colorado State University	330
D-7	Acoustic Velocity Ratios in Solid Argon at 75 K up to Static Pressures of 150 kbar, C. G. HOMAN, J. FRANKEL, D. P. KENDALL, J. A. BARRETT and T. E. DAVIDSON, U.S. Army Benet Weapons Laboratory, Watervliet Arsenal	339

E. Melting Phenomena

E-1	The Thermodynamics of Melting for Alkali Metals, I. N. MAKARENKO, A. M. NIKOLAENKO AND S. M. STISHOV, Institute of Crystallography of Academy of Sciences. .	347
E-2	Melting Curves of Iron at High Pressures, E. BOSCHI, D. FAZIO and F. MULARGIA, Università di Bologna	357
E-3	Determination of Melting Entropy by the Measurement of the Volume Change of Melting at High Pressure, P. W. MIRWALD, Ruhr-Universität-Bochum	361

E-4	Entropy Determined from Heat of Compression at High Pressure for Benzene and Carbon Tetrachloride, P. PRUZAN and L. TER MINASSIAN, Laboratoire de Chimie Physique, and A. SOULARD, Laboratoire de Minéralogie Cristallographie	368
-----	--	-----

F. Thermal Properties of Fluids

F-1	Transport in Dense Fluids, D. W. OXTOBY, Université Paris-Nord	379
F-2	An Evaluation of the PNM Dense Gas Transport Theory, R. J. GOVERNALE and S. E. BABB, JR., The University of Oklahoma	390
F-3	Equation of State for Fluids at High Densities - Hydrogen Isotope Measurements and Thermodynamic Derivations, D. H. LIEBENBERG, R. L. MILLS and J. C. BRONSON, University of California, Los Alamos Scientific Laboratory	395
F-4	Equation of State of Dense Fluids: Comparison with Machine Calculations and Estimations from Pressure Dependence of Dielectric Constant Measurements, D. VIDAL and M. LALLEMAND, Centre Universitaire Paris Nord	408
F-5	An Equation of State for the Static Dielectric Constant of Water from 0 to 550°C and up to 5 kbar, M. UEMATSU, Keio University, and E. U. FRANCK, Universität Karlsruhe	415
F-6	Thermophysical and Dielectric Properties of Methanol and Related Compounds to 350°C and 5 kbar, E. U. FRANCK, R. TÁANI and R. DEUL, Universität Karlsruhe	420
F-7	Piezo-Optic Behavior and the Equation of State of Liquids, K. VEDAM and P. LIMSUWAN, The Pennsylvania State University	421
F-8	Water Hugoniot Measurements in the Range 30 to 220 GPa, A. C. MITCHELL and W. J. NELLIS, Lawrence Livermore Laboratory, University of California	428

G. Spectroscopic Studies

G-1	The Effect of Pressure on the Raman Spectra in Trigonal Se and Te, S. MINOMURA and K. AOKI, University of Tokyo, and N. KOSHIZUKA and T. TSUSHIMA, Electrotechnical Laboratory	435
G-2	New High-Pressure Phase Transitions in Potassium Cyanide, W. DULTZ, H. KRAUSE and J. PLONER, Universität Regensburg	441