

# Contents

|                             |     |
|-----------------------------|-----|
| <i>List of Contributors</i> | v   |
| <i>Preface</i>              | vii |

## Chapter 1. **An Introduction to the Nature and Technology of Hydrides**

JAMES P. BLACKLEDGE

|                                      |    |
|--------------------------------------|----|
| 1-1 Classification of the Hydrides   | 2  |
| 1-2 Deuterides and Tritides          | 7  |
| 1-3 Massive Hydrides                 | 8  |
| 1-4 Uses for Metal Hydrides          | 11 |
| 1-5 Hydrogen Embrittlement in Metals | 14 |
| References                           | 19 |

## Chapter 2. **Hydrides in Nuclear Reactor Applications**

WILLIAM M. MUELLER

|                                            |    |
|--------------------------------------------|----|
| 2-1 Neutron Physics                        | 22 |
| 2-2 Hydrides in Reactor Components         | 30 |
| 2-3 Moderators                             | 31 |
| 2-4 Metal Hydrides as Moderator Materials  | 33 |
| 2-5 Reflectors                             | 38 |
| 2-6 Metal Hydrides as Reflector Materials  | 40 |
| 2-7 Shields                                | 41 |
| 2-8 Metal Hydrides as Shielding Materials  | 43 |
| 2-9 Controls                               | 45 |
| 2-10 Metal Hydrides as Control Materials   | 45 |
| 2-11 Hydrogen Containment                  | 45 |
| 2-12 Radiation Stability of Metal Hydrides | 47 |
| 2-13 Thermal Stability of Metal Hydrides   | 48 |
| References                                 | 48 |

### Chapter. 3. The Thermodynamics of Metal-Hydrogen Systems

RUDOLPH SPEISER

|                                                              |    |
|--------------------------------------------------------------|----|
| 3-1 Adsorption of Hydrogen on Metal Surfaces                 | 51 |
| 3-2 Solution of Hydrogen in Metals and Formation of Hydrides | 69 |
| References                                                   | 87 |

### Chapter 4. Statistical Mechanics of Metal-Hydrogen Systems

RUDOLPH SPEISER

|                                               |     |
|-----------------------------------------------|-----|
| 4-1 Ideal Solutions of Hydrogen in Metals     | 91  |
| 4-2 Interaction of Hydrogen Atoms in Solution | 97  |
| 4-3 Lattice Defects in the Hydride Phase      | 114 |
| 4-4 Summary                                   | 117 |
| References                                    | 117 |

### Chapter 5. Chemistry of Metal Hydrides as Related to Their Applications in Nuclear Technology

JAMES P. BLACKLEDGE

|                                                                 |     |
|-----------------------------------------------------------------|-----|
| 5-1 Chemical Reactions                                          | 119 |
| 5-2 Preparation of the Hydrides                                 | 141 |
| 5-3 Analytical Techniques for Determination of Hydrogen Content | 156 |
| References                                                      | 161 |

### Chapter 6. Saline Hydrides

CHARLES B. MAGEE

|                                                                 |     |
|-----------------------------------------------------------------|-----|
| 6-1 General Information                                         | 165 |
| 6-2 Dissociation Behavior of the Saline Hydrides                | 171 |
| 6-3 Properties of the Saline Hydrides                           | 199 |
| 6-4 Ionic Crystal Theory Applied to the Saline Hydrides         | 223 |
| 6-5 Preparation of the Saline Hydrides and of Beryllium Hydride | 232 |
| References                                                      | 236 |

### Chapter 7. Zirconium Hydrides and Hafnium Hydrides

RICHARD L. BECK AND WILLIAM M. MUELLER

|                                     |     |
|-------------------------------------|-----|
| 7-1 Zirconium Hydride               | 241 |
| 7-2 Zirconium-Hydrogen Phase System | 242 |

|     |                                         |     |
|-----|-----------------------------------------|-----|
| 7-3 | Properties of Zirconium Hydrides        | 286 |
| 7-4 | Hafnium Hydride                         | 321 |
| 7-5 | Hafnium-Hydrogen Phase System           | 321 |
| 7-6 | Zirconium-Hafnium-Hydrogen Phase System | 326 |
|     | References                              | 330 |

## Chapter 8. Titanium Hydrides

WILLIAM M. MUELLER

|     |                                                                |     |
|-----|----------------------------------------------------------------|-----|
| 8-1 | Titanium-Hydrogen Phase System                                 | 336 |
| 8-2 | Thermodynamic Properties of the Titanium-Hydrogen System       | 365 |
| 8-3 | Physical and Mechanical Properties of Titanium-Hydrogen Alloys | 367 |
| 8-4 | Titanium-Base Alloy-Hydrogen Systems                           | 375 |
|     | References                                                     | 382 |

## Chapter 9. The Rare-Earth Hydrides

WILLIAM M. MUELLER

|     |                                                    |     |
|-----|----------------------------------------------------|-----|
| 9-1 | General Characteristics of the Rare-Earth Hydrides | 386 |
| 9-2 | Specific Hydrides and Deuterides                   | 393 |
|     | References                                         | 438 |

## Chapter 10. Yttrium and Scandium Hydrides

JAMES P. BLACKLEDGE

|      |                                                |     |
|------|------------------------------------------------|-----|
| 10-1 | Yttrium Hydride                                | 441 |
| 10-2 | Phase Relations in the Yttrium-Hydrogen System | 443 |
| 10-3 | Microstructure of Hydrided Yttrium             | 445 |
| 10-4 | Properties of Yttrium Hydrides                 | 450 |
| 10-5 | Scandium Hydride                               | 480 |
| 10-6 | The Scandium-Yttrium-Hydrogen System           | 484 |
|      | References                                     | 488 |

## Chapter 11. The Actinide Hydrides

GEORGE G. LIBOWITZ

|      |                                                       |     |
|------|-------------------------------------------------------|-----|
| 11-1 | Preparation and Kinetics of Formation of the Hydrides | 491 |
| 11-2 | Phase Relations                                       | 495 |
| 11-3 | Crystal Structures                                    | 502 |
| 11-4 | Thermodynamic Properties                              | 506 |
| 11-5 | Electrical and Magnetic Properties                    | 515 |
| 11-6 | Metallography and Mechanical Properties               | 519 |

|                                                     |     |
|-----------------------------------------------------|-----|
| 11-7 Other Information on Actinide-Hydrogen Systems | 523 |
| 11-8 Three-Cornpollent Systems                      | 531 |
| References                                          | 540 |

## Chapter 12. The Covalent Hydrides and Hydrides of the Groups V to VIII Transition Metals

**BERNARD SIEGEL AND GEORGE G. LIBOWITZ**

|                                                                                                           |     |
|-----------------------------------------------------------------------------------------------------------|-----|
| 12-1 Group 1B—Copper, Silver, and Gold                                                                    | 546 |
| 12-2 Group 11—Beryllium, Magnesium, Zinc, Cadmium, and Mercury                                            | 550 |
| 12-3 Group 111—Boron, Aluminum, Gallium, Indium, and Thallium                                             | 557 |
| 12-4 Silicon, Germanium, Tin, and Lead                                                                    | 585 |
| 12-5 Group V Transition-Metal Hydrides—Niobium, Vanadium, and Tantalum                                    | 592 |
| 12-6 Groups VI and VII—Chromium, Molybdenum, Tungsten, Manganese, Technetium, and Rhenium                 | 621 |
| 12-7 Group VIII Metals—Iron, Cobalt, Nickel, Ruthenium, Rhodium, Palladium, Osmium, Iridium, and Platinum | 627 |
| References                                                                                                | 652 |

## Chapter 13. Fabrication of Hydrides

**COY L. HUFFINE**

|                                       |     |
|---------------------------------------|-----|
| 13-1 Preparation of the Hydride       | 676 |
| 13-2 Fabrication of Powdered Hydrides | 686 |
| 13-3 Machining and Grinding           | 705 |
| 13-4 Cladding and Canning             | 709 |
| References                            | 744 |

*Author Index* 749

*Subject Index* 769