ULTRACONDENSED MATTER BY DYNAMIC COMPRESSION

Dynamic compression is an experimental technique with interdisciplinary uses, ranging from enabling the creation of ultracondensed matter under previously impossible conditions to understanding the likely cause of unusual planetary magnetic fields. Readers can now gain an intuitive understanding of dynamic compression; clear and authoritative chapters examine its history and experimental method, as well as key topics including dynamic compression of liquid hydrogen, rare gas fluids and shock-induced opacity. Through an up-to-date history of dynamic compression research Nellis also clearly shows how dynamic compression addresses and will continue to address major unanswered questions across the scientific disciplines. The past and future role of dynamic compression in studying and making materials at extreme conditions of pressure, density and temperature is made clear, and the means of doing so are explained in practical language perfectly suited for researchers and graduate students alike.

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Preface

The science of dynamic compression began in 1870 when W. J. M. Rankine published a paper on the conservation equations of momentum, mass and energy across the front of a supersonic shock wave in an ideal gas. The paper was published in *Philosophical Transactions of the Royal Society of London*. Rankine was a professor at the University of Glasgow and a colleague of William Thomson, Lord Kelvin, also of the University of Glasgow.

Supersonic hydrodynamics was developed mathematically in Western Europe in the last half of the nineteenth century. H. Hugoniot derived Rankine's conservation equations on a more general basis in the 1880s. With the advent of quantum mechanics in the 1920s, dynamic compression would probably have been completely forgotten but for the threat of World War II in the 1930s. In 1940, H. Bethe and E. Teller wrote the first theoretical treatment of thermal equilibration in the front of a shock wave in an ideal gas.

World War II generated substantial governmental funding for experimental facilities in both the United States and the Soviet Union, which enabled tests of previous theoretical predictions about shock wave propagation. A major emphasis of that period was development of fast experimental techniques to measure pressure-volume data under shock compression using the Rankine-Hugoniot shock wave conservation equations.

In the 1950s, researchers using dynamic and static compression combined to determine pressure, density and likely crystal structure of the α-ε transition of Fe at 13 GPa. That determination was the first generally accepted phase transition observed under shock compression and with that acceptance shock compression was recognized generally as a science by the static high pressure community. It was also the first fixed-point pressure standard derived with dynamic compression.

In subsequent years, dynamic compression experiments were performed primarily in defense laboratories and in a few universities and companies. As a result, few textbooks have been written on dynamic compression, although several have been

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written on shock compression, which is a particular type of dynamic compression. Because of this, researchers have often had to learn about dynamic compression from a relatively few published papers and a few unpublished reports. Thus research in dynamic compression had become essentially isolated from the scientific community.

Then it happened. In 1996, metallic fluid H (MFH) was made under dynamic compression at finite temperatures in a crossover from semiconducting H to poor metallic (degenerate) H with measured Mott's minimum metallic conductivity. This crossover completes at the density of the insulator-metal transition from solid H_2 to solid H predicted by Wigner and Huntington in 1935. Finding MFH experimentally gave dynamic compression visibility it never had, but there also suddenly arose the need to explain what it is exactly. There was, however, no easy way to explain it – no book to which to refer people.

So I have written this book to be of general interest to undergraduate and graduate students, for professors that teach them and for research scientists at national laboratories and in industry who need to know it. This book is not intended to be an all-inclusive review. It is about ideas and concentrates on pressures greater than ~10 GPa, below which traditional publications cover shock compression. I am trying to convey the idea that dynamic compression at much higher dynamic pressures is a vehicle for novel scientific research that has lead to exciting scientific discoveries. To this end this book contains a chapter on the basics of dynamic compression needed to design and understand results of such experiments and a few examples that illustrate how this technique connects to understanding general scientific questions that have been unresolved for years.

Implied by these discussions is the fact that a new regime of thermodynamic conditions has been opened up for experimental investigations and associated theory. Dynamic compression discussed herein is an experimental technique, not an academic discipline. Opportunities are available in physics, chemistry, planetary science, materials science and other fields. Uses of dynamic compression are limited only by the imagination of its practitioners. In this regard I am reminded of the words of William Fowler, former President of the American Physical Society: “We look forward to the future of our profession as an intellectual enterprise for the individual and as a practical enterprise for society.”

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