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MASTER

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The Shock Wave Physics Group located at Ancho Canyon was formed in the early 1950's to provide equation-of-state (EOS) data for the high pressure physics community. One of the early advances which greatly facilitated obtaining accurate EOS data was the impedance matching technique of J. M. Walsh¹. With this technique the Hugoniot of over 500 materials^{2,3,4} have been measured. Currently the EOS effort at M-6 is largely confined to the two-stage gun facility where many of the previously measured Hugoniot are being extended to higher pressures. Most of the other shock wave studies are directed toward a better understanding of the shock process and physical properties of the shocked state. The experimental facilities and personnel being utilized for these investigations are listed in Table 1 along with some of the most recent studies.

Phase changes under shock loading have been observed for many materials. A manifestation that a phase change has occurred is a discontinuity both in magnitude and slope of the U_s-U_p relation. For some phase changes with small volume differences and similar elastic constants there are no observable discontinuities either in value or slope of the U_s-U_p curve. To detect these changes of state a more sensitive probe is needed. The optical analyzer developed by McQueen⁵ is a detector with sufficient sensitivity to see small wave velocity discontinuities in the shock state. Consequently some of the more subtle phase changes can be detected. Recently the solid-solid ($\alpha \rightarrow \gamma$) phase transition at 200 GPa in iron has been observed along with the γ iron to melt transition at 250 GPa⁶. Both these transitions are undetectable from the U_s-U_p Hugoniot curve. The Lagrangian wave interaction diagram for the optical analyzer is shown in Fig. 1. Upon symmetric impact of a thin flyer with a step wedge target shock waves are propagated both in the target and flyer plate. When the shock wave reaches the

Fig. 1. Lagrangian Wave Interaction Diagram

**TABLE I Compressed Gas Gun, Two-stage Gas Gun and
High Explosive Facilities**

Facilities:	51 mm diam single stage compressed gas gun (0.02 + 1.00 km/s), 29 mm diam two-stage light gas gun (3 + 8 km/s) and HE firing site using explosive lenses from 102 mm to 305 mm diam.
Diagnostics:	Tektronix 7903 (0.7 ns resolution) and Tektronix 519 (0.3 ns resolution) oscilloscopes, radiation detectors (< 1 ns response), ASM probe (1 ns/cm coil diam), Manganin gauges (> 15 ns response), free surface capacitor (15 ns response), flash radiography, rotating mirror framing and streak cameras, framing and streak image converter camera.
Recent Studies:	<ul style="list-style-type: none"> • Melting of iron under core conditions. • High pressure equation-of-state of SiO₂. • Thermodynamic properties for shocked porous iron. • High pressure strength of metals at pressures exceeding 100 GPa. • Radiation technique for very accurate shock velocity measurements. • Melting of Al and Cu on the Hugoniot. • Optical technique for determining rarefaction wave velocities at multimegabar pressures. • Synthesis of superconducting Al₅Nb₃Si by shock compression. • Mechanisms for rapid phase transformation of Nb₃Si under shock conditions.
Principal Investigators:	Joseph N. Fritz, Stanley P. Marsh, Robert G. McQueen, Jerry A. Morgan, Charles E. Morris, Hart W. Olinger, Steve C. Schmidt, John W. Shaner
Technical Support:	Austin D. Bonner, Walter W. Quintana, Dennis L. Shampine, Robert S. Medina, Charles W. Caldwell, Felix A. DePaula, Connie N. Gomez, Maria T. Roybal

backside of the flyer plate a forward rarefaction is generated which ultimately overtakes the forward going shock front in the transparent analyzer causing a decrease in the radiation. The time interval Δt between initial emergence of the shock at the target-analyzer interface until overtake by the rarefaction wave is a linear function of target thickness and when extrapolated to zero determines the target thickness where the rarefaction would have overtaken the shock wave at the target-analyzer interface. Through this extrapolation procedure the hydrodynamic perturbation due to the presence of the analyzer is eliminated and therefore a true in situ overtake velocity is obtained. The rarefaction wave velocity C at pressure is given by ⁵

$$C = U_B (\rho_0/\rho) (R+1)/(R-1) \quad (1)$$

where R is the ratio of target to flyer plate thickness for Δt equals zero. Experimentally determined R values of a few tenths of a percent precision are typical.

Another technique useful for studying the physical properties of the shock state is the axially symmetric magnetic (ASM) probe. A paper describing measurements of the quasi-elastic structure in 2024 Al to 90 GPa and in OFHC Cu to 140 GPa is presented in these conference proceedings. The ASM probe has also been used to study insulators, detonating explosives⁸ and HE driven metal plates. Illustrated in Fig. 2 is the construction of the ASM probe assembly designed to measure the quasi elastic structure in metals. A permanent magnet provides a nonuniform steady magnetic field through which the target surface is accelerated. Because of the magnetic field, eddy currents are generated in the moving target surface which produce a time-varying magnetic field. These time-varying fields induce a voltage signal in a pickup coil from which the velocity of the metal plate may be obtained. A wave profile in 2024 Al at 55 GPa is shown in Fig. 3. From this wave

Fig. 2. ASM Probe Assembly

Fig. 3. Wave Profile in 2024 Al

profile the longitudinal modulus, bulk modulus and shear strength of the material at pressure may be calculated.⁹

Another major interest at M-6 is the use of pulsed megagauss fields as a tool for solid state research for high-energy pulsed power sources and as pressure sources. Max Fowler, who is the developer of the cylindrical flux compression generator,¹⁰ directs this research effort. Some physical characteristics of the explosive flux compression generators developed at M-6 are listed in Table II and illustrated in Fig. 4. All the generators have relatively large work volumes. Some of the recent studies using

TABLE II Pulsed Megagauss Field Facility

Facilities:	Single stage flux compressor: fields to 150 T, > 1 μ s 90% to peak, experimental volume 76 mm long to 19 mm diam. Two stage flux compressor: fields to 250 T, 5 μ s 90% to peak, experimental volume 76 mm long to 19 mm diam. Cylindrical flux compressors: fields > 1000 T, < 1 μ s 90% to peak, experimental volume 10-20 mm long to 7 mm diam. Capability of cryogenic experimentation.
Diagnostics:	Time resolved rotating mirror spectrographs, coverage 200-680 nm, various light sources including quasi-continuous, and variety of laser sources, wide variety of electrical measuring techniques, flash radiography, image intensifiers, rotating mirror framing and streak cameras, framing and streak image converter camera.
Recent Studies:	<ul style="list-style-type: none"> • Magneto-resistance of Bismuth. • Isentropic compression of deuterium. • Faraday rotation of many materials. • Excitonic absorption spectrum of GaSe. • Preliminary mapping of B-T spin-flip to paramagnetic phase line for MnF_2. • Zeeman spectra at 500 T fields.
Principal Investigators:	Robert S. Caird, Dennis J. Erickson, C. Max Fowler, Bruce L. Freeman, Jim H. Goforth
Technical Support:	Jim C. King, A. Richard Martinez, Ralph R. Roy, Steve E. Salazar, David T. Torres

Fig. 4. Flux Compression Generators: a) Single Stage b) Two-Stage c) Cylindrical

these systems are listed in Table II along with the principal investigators and supporting personnel. Presently much of the effort in the magnetic program is directed toward the development of pulsed power sources for physics research.

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