From Sound Waves to Stars

Teller's Contributions to Shock Physics

January 15, 2008, marks the 100th anniversary of Edward Teller's birth. This highlight is the first in a series of 10 honoring his life and contributions to science.

THROUGHOUT his career, Edward Teller displayed a genius for building bridges of discovery between basic and applied science. In the field of shock physics, papers bearing his name are on both sides of the bridge.

Shock physics is the study of the behavior of materials as a sharp jump in density passes through them. The shock can be generated on any scale—from the action of a supernova to an earthquake, a hammer blow, or even a single photon. The material affected can vary as well—from the substance of stars at high energy density to matter under terrestrial conditions.

Teller's initial interest in shock physics was a natural outgrowth of his work on the quantum dynamics of atoms and molecules. In 1936, Teller and Soviet physicist Lev Landau coauthored a paper proposing a theory about how a sound wave, which essentially is a very weak shock wave, dissipates in a molecular gas. The paper trail leads next to an unpublished but oft-cited paper written in 1941 by Teller and physicist Hans Bethe, "Deviations from Thermal Equilibrium in Shock Waves." This work describes the results from a study commissioned by the U.S. Army to examine how shock waves interact with gases. Their research, which took into account the microscopic properties of a shocked medium, proved influential to later studies in many areas, including the behavior of vehicles reentering the atmosphere.

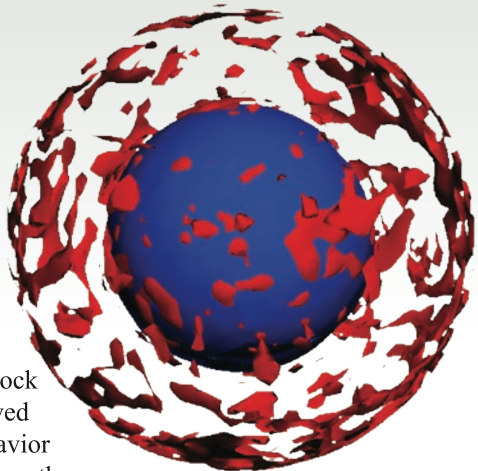
From here, Teller's renown in the field began to grow. While lecturing at Columbia University, he was approached by Arthur Kantrowitz, a physics graduate student who also worked as an applied scientist at Langley Air Force Base. In his doctoral research, Kantrowitz had developed novel methods for measuring the thermal behaviors of shocks in gases. He asked Teller to sponsor his dissertation. In *Memoirs*, Teller says, "Arthur knew much more about the subject than I did. But when I started to demur . . . Arthur pointed out that my work with Landau, and a recent note that Bethe and I had published, made it impossible for me to deny all knowledge of the subject." Teller agreed to be his advisor and thus became a mentor in the arena of shock physics. Kantrowitz later became a leading expert in the field of hypersonic hydrodynamics.

When the discovery of fission was announced in 1939, Teller was intrigued and began to consider the potential uses of nuclear energy produced in both fission and fusion reactions. In 1942, he joined the Manhattan Project, to help develop the nation's first atomic bomb. From the beginning, shock physics was an important part of that research as scientists worked to understand how the shock waves produced by high explosives and nuclear energy release would affect the various materials being used in a nuclear weapon.

Teller's interest in high-energy-density physics and shock physics continued after the war. For example, in 1949, he coauthored the important paper "Magneto-Hydrodynamic Shocks" with physicist Frederick de Hoffman, generalizing shock "rules" to relativistic magnetohydrodynamics, which studies the interaction of density and magnetic-field pulses in electrically conducting liquids or gases, such as molten metal or plasma. Furthermore, Teller initiated significant work during and after the war on equation-of-state models, a key ingredient in understanding shock propagation.

Edward Teller enjoyed playing the piano for his wife, Mici. (Photograph courtesy of Jon Brenneis.)

It is not surprising then, given the shock physics thread weaving through his life at the intersection of basic and applied science, that Lawrence Livermore National Laboratory—the laboratory cofounded by Teller and Ernest O. Lawrence in 1952—should become known for its shock physics experiments and



Results from Livermore's three-dimensional hydrodynamics model of a red giant star show that, deep in the star's interior, hydrogen-rich clouds (red) float above the hydrogen-burning shell (blue).

the computer codes and simulations based on such data. Livermore's early shock physics experiments allowed scientists to study the behavior of gases, fluids, and solids as they are exposed to shock waves. High-fidelity data from these experiments improve the accuracy of simulations used to replicate past underground nuclear tests and thus are crucial to today's Stockpile Stewardship Program, which ensures the safety and reliability of the nation's nuclear weapons.

Shock physics continues to be an important research area at the Laboratory. Experimental platforms such as gas guns, lasers, and diamond anvil cells allow researchers to elucidate the equations of state of shocked materials and improve their understanding of complex materials such as plutonium. (See the article on p. 23.) In 1994, shock experiments at Livermore yielded the first observation of fluid metallic hydrogen. Using gas guns and lasers, Livermore scientists produce shocks that create extraordinarily high pressures, mimicking the extreme conditions in an explosion, the detonation of a nuclear weapon, an inertial fusion experiment, a star, or the impact of a large meteorite, were one to hit the Earth. Shock physics experiments helped determine the melting point for iron in Earth's core, while data about hydrogen and other molecular fluids such as water are allowing scientists to better understand the interiors of giant planets in our solar system.

Whether it was defining the interactions of sound waves with gases or exploring the behavior of metals under extreme conditions, Teller excelled at making connections between theory and applied science, including the field of shock physics. This approach—taking what is known and what can be done, and pushing beyond—is one that continues at Lawrence Livermore to this day.

—Ann Parker

Key Words: Edward Teller, magnetohydrodynamics, Manhattan Project, shock physics.

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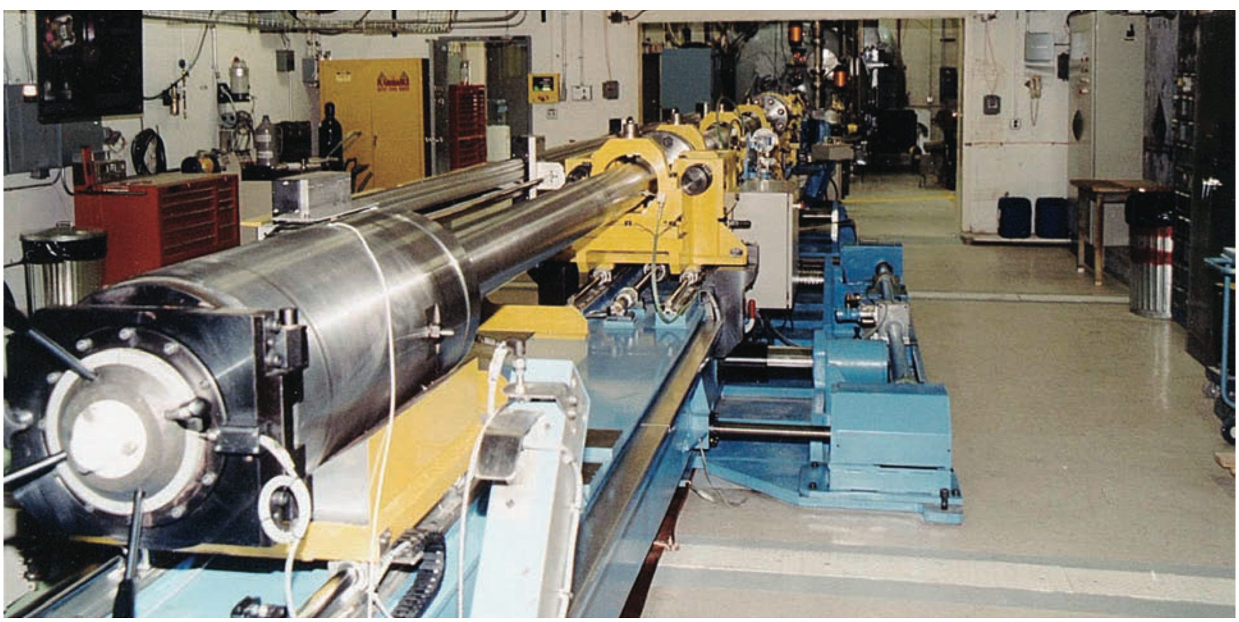

The two-stage gas gun at the Joint Actinide Shock Physics Experimental Research Facility in Nevada is one method used to perform shock physics experiments. (Photograph courtesy of the Nevada Test Site.)