The last few years have seen a dramatic upsurge in shock compression studies of liquid hydrogen and deuterium. We have seen the first shock temperature measurements, measurements of electrical conductivity and sound velocity, and most recently, equation-of-state (EOS) measurements using very large laser drivers. These experiments have changed our understanding of dense hydrogen, or rather, they have forcefully emphasized how little we actually understand the simplest and most abundant material in the universe. This brief abstract will serve as a summary of the most recent experimental results.

The Hugoniot EOS of hydrogen and deuterium was measured by Van Theil and Alder [1], and Nellis, et al. [2] They made single and double shock measurements, and a model was developed by Ross, et al. [3] which fit the data very well over the entire range of pressures and densities, up to 80 GPa and roughly 1 g/cm³. A few years ago, Holmes, et al. [4] reported shock temperature measurements which led a change in our view of shocked hydrogen. The temperatures measured in the reshock state at 80 GPa were much lower than predicted by the model. They proposed a new model for shocked hydrogen, in which the molecular dissociation energy decreased as density increased. In this case, a small amount of molecular dissociation at high densities absorbed the energy that would otherwise heat the system. This new model was successful in matching the data, again over the entire range of pressures and densities, and also agreed with the temperature measurements as shown in Figure 1.

Extrapolation of this model on the Hugoniot to > 100 GPa (well beyond the current capability of impact experiments of 30 GPa) predicted substantially higher compressibility of hydrogen, up to roughly 6-fold compression at 150 GPa. That is to be compared with the SESAME table for which the tabulated value is about 0.7 g/cm³. If true, the higher compressibility makes inertial confinement fusion (ICF) using lasers easier, and requires changes in target design. This provided a strong stimulus to perform Hugoniot EOS experiments at pressures above 100 GPa. The only way to reach these pressures currently is using the same large lasers built for ICF. However, such an application poses severe challenges. While attempts to determine the EOS of materials at high pressures using lasers have been made for two decades, they have not been particularly successful. Laser-driven shock experiments suffer by comparison with other methods for a variety of reasons: (1) the difficulty of making absolute measurements which require simultaneous determination of mass and shock velocities; (2) the problem of preheat from x-rays or energetic electrons which heat the sample and possibly drive weak shocks into it from the preheated walls; (3) the difficulty of making the shock steady as it traverses the sample; (4) it is difficult to make a uniform, planar shock over a large area; (5) the space and time scales (μm and ns) make accurate measurements very challenging.

However, a serious attempt was made to address each of these difficulties, and Da Silva, et al.
measurements of the Hugoniot of liquid deuterium up to 200 GPa. Those results are summarized in Figure 2. This provides evidence that hydrogen and deuterium are much more compressible than believed previously. However, even the apparent success of the dissociation model in predicting these results must be viewed in the broader perspective in which the detailed processes which lead to the large compressibility remain to be determined.

On the other hand, another process which can absorb energy in internal degrees of freedom is ionization. The production of free carriers in hot, compressed hydrogen and deuterium can be assessed by measuring the electrical conductivity during the shock process. Using quasi-isentropic compression (in which the shock reverberates between Al2O3 plates), Weir, et al. [6] reported the discovery of metallic hydrogen. Their data is summarized in Figure 3, in which the resistivity of both isotopes is plotted versus pressure. The plateau for P > 140 GPa indicates that the material has become metallic. This finding will have a significant impact on our understanding of hydrogen at high densities and temperatures, and also for the Jovian planets in which metallic hydrogen may constitute most of the volume.