LET'S MAKE SOME IMPACT(S)! AN OVERVIEW OF IMPACT AND SHOCK-WAVE EXPERIMENTS FOR PLANETARY SCIENTISTS.

C. Hamann[1], [1]Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung,
Invalidenstr. 43, 10115 Berlin, Germany (christopher.hamann@mfn.berlin).

Introduction: Impact cratering is now widely recognized as one of the fundamental planetary processes that shape the surfaces of solid bodies in our solar system. Among the unique consequences of hypervelocity impacts is the generation of a shock front that compresses both the projectile as well as the target through which it travels and which conserves mass, momentum, and energy, but not entropy [1]. The shock wave is followed by a rarefaction wave, which forms at the rear (free) surface of the projectile and which adiabatically decompresses the projectile and the compressed target back to the reference pressure. The outcome of these processes is acceleration, deformation of target material [2], and excavation of a bowl-shaped transient crater as well as solid-state deformation [3], melting [4], and vaporization [5] of projectile and target materials upon decompression. Impactites collected from terrestrial impact structures or sampled in extraterrestrial materials provide valuable insights into the products of impacts. However, with the exception of direct observation of impact flashes, the processes that operate during crater formation are virtually impossible to directly observe in nature. A variety of laboratory shock-wave experiments are therefore consulted to probe shock compression of relevant planetary materials and to shed light onto different aspects of crater formation. Here, an overview of common dynamic-compression experiments and applications in the planetary sciences is given.

Experimental Setups, Typical Applications, and Limitations: Due to the dynamic, highly transient nature of shock-wave compression and the extreme pressures and temperatures involved, shock-wave experiments differ from static high-pressure experiments (e.g., diamond anvil cell experiments) or isobaric heating in furnaces commonly used in classic petrology. Two different approaches, or variants thereof, are typically pursued: (1) Shock-recovery or shock-reverberation experiments, in which a sample is enclosed in a metal container that is then compressed by a planar shock front generated, for example, by the impact of a metal flyer plate. (2) Two-stage light-gas gun experiments, in which a projectile is accelerated to typically between 1 and 7 km/s (much higher velocities are difficult to achieve for macroscopic projectiles due to technical limitations) and impacts a target. Variations of these techniques include, but are not limited to, ablation and acceleration of a flyer plate by high-power lasers [6], shock-recovery experiments with spherical configurations [7], or combinations of shock-recovery and two-stage light-gas gun experiments [8].

Shock-reverberation experiments have traditionally been used to delineate the shock response of solids and to characterize the resulting phase changes in pressure–temperature space. They are, thus, the basis of currently used shock classification schemes that link petrographic observations to certain, material dependent shock-pressure or post-shock temperature ranges [3]. Common limitations of this technique are reflections of the shock wave at the surfaces of the metal container, which results in several 'ring-up' steps in which the peak pressure increases abruptly, and in the confining nature of the metal container that prevents degassing of volatiles during decompression. Two-stage light-gas gun experiments overcome these problems and may simulate singular shock compression in an open system, such as in natural impacts, more faithfully. Such experiments are used, for example, to study the mechanics of crater formation [9,10], regolith formation of airless bodies [11], the fate of the projectile [12,13], the chemical interaction and modification of projectile and target materials [14], or impact-induced release of volatiles during decompression [15]. However, they are afflicted with crater formation and ejection of shocked materials, which makes reconstruction of pre-impact positions difficult and necessitates equipment for space-resolved sampling of ejecta. The various techniques, some typical applications, and limitations are summarized and discussed here.

Outlook: Shock-wave experiments provide insight into shock compression of condensed matter, are used to construct equations of state, and shed light onto various aspects of impact-crater formation. Recent developments have increased the range of pressures and temperatures achievable in laboratory experiments [6,7,16,17], which opens possibilities to probe regions of phase space that have previously been difficult to achieve. Combination of laboratory experiments with numerical modeling is particularly fruitful [18], and multidisciplinary approaches may provide insight into processes of impact cratering that were previously difficult to study [8,9,15,18].

References: [1] Melosh H. J. (1989) Impact Cratering: A Geologic Process, Oxford University Press. [2] Rae A. S. P. et al. (2021) *Icarus* 370:114687. [3] Stöffler D. et al. (2018) *Meteoritics & Planetary Science* 53:5–49. [4] Pierazzo E. et al. (1997) *Icarus* 127:408–423. [5] Kraus R. G. et al. (2012) *Journal of Geophysical Research* 117:E09009. [6] Kurosawa K. et al. (2010) *Geophysical Reseach Letters* 37: L23203. [7] Kohout T. et al. (2020) *Astronomy & Astophysics* 639:A146. [8] Hamann C. et al. (2022) *LPSC LIII*, Abstract #2020. [9] Wünnemann K. et al. (2016) *Meteoritics & Planetary Science* 51:1762–1794. [10] Cline C. J. and Cintala M. (2021) *LPSC LII*, Abstract #1034. [11] Hörz F. and Cintala M. (1997) *Meteoritics & Planetary Science* 32:179–209. [12] Daly R. T. and Schultz P. H. (2018) *Science Advances* 4:eaar2632. [13] Daly R. T. and Schultz P. H. (2016) *Icarus* 264:9–19. [14] Ebert M. et al. (2013) *Meteoritics & Planetary Science* 48:134–149. [15] Kurosawa K. et al. (2021) *Communications Earth & Environment* 2:146. [16] Kadono T. et al. (2010) *Journal of Geophysical Research* 115: E04003. [17] Kraus R. G. et al. (2015) *Nature Geoscience* 8:269–272. [18] Kenkmann T. et al. (2018) *Meteoritics & Planetary Science* 53:1543–1568.