ENERGY PARTITIONING, MELTING, AND VAPORIZATION FOR IMPACT ON FINITE SIZED PLANETS; Catherine L. Smither and Thomas J. Ahrens, Lindhurst Laboratory of Experimental Geophysics, Seismological Laboratory, California Institute of Technology, Pasadena CA 91125

Recently, the Smoothed Particle Hydrodynamics (SPH) method [1] has been used to model a variety of specific problems if shock effects in self-gravitating planetary systems, testing, for example, hypotheses about subjects such as the formation of the Moon [2] and the possible stripping of Mercury's mantle [3].

Our initial simulations were for a silicate target body 800 km in radius; we varied the size of the impactor from 10 to 40 percent of the target radius for impact velocities from 5 to 20 km/sec and modeled both normal impacts and impacts at 60 degrees from the zenith. A representative run is shown figures 1 and 2. The target is 880 km in radius; the impactor has a radius of 350 km, and hit the target obliquely at a velocity of 10 km/sec. The velocities of the particles are shown in figure 1; the first panel shows the system shortly after the impact, at time T=7. (Time is expressed in the non-dimensional unit T = (time in seconds)*(impact velocity)/length scale). Thus in this case, one time unit is 10 seconds. In the first panel, the part of the target closest to the area of impact is most affected; the antipodes of the planet have not yet experienced their maximum shock. The next panel is 20 T later; a substantial amount of material is being ejected from the system at maximum speeds of 8 km/sec. The free surface velocity of the antipodal material, 6.6 projectile radii from the point of impact is 12 km/sec, which is close to the 10 km/sec predicted for one-dimensional impact [4]. At later times, the particles which did not achieve escape velocity are drawn by gravity back into the system. In this case, 18% of the total material in the system was ejected at greater than escape velocity. This is about twice that calculated for impact of a silicate body on a half-space with an escape velocity of 5 km/sec [5]. All of the impactor was shocked to internal energies above that required for melting and 6% was vaporized. In this simulation, 2.6 projectile masses were melted; this may be compared to the 3.0 projectile masses calculated for impact into a half-space [6]. In the target, 13% of the material was melted; no vaporization was indicated. A plot of the total energy in the system is shown in figure 2. Energy is normalized to the total amount of energy in the system at the start of the run. Initially, almost all the energy is in the kinetic energy of the impactor; after the impact the internal energy of the target is increased due to the effect of the shock. There is a large amount of energy still in the impactor, as its particles are still traveling at a high velocity. This result differs markedly from the half-space calculations, where 80% of the total energy in the system remains in the target as heat. Figure 3, adapted from a figure in [7], compares the results of this study with the half-space model. The boxes plotted show the partitioning of energy for impact velocities 10 and 20 km/sec. The proportional amounts of kinetic energy in the target and internal energy of the impactor are in close agreement; the SPH model predicts a much higher fraction of the total energy in the kinetic energy of the impactor.

When the same impactor hits the same target at 20 km/sec, 33% of the total material in the system is ejected at greater than escape velocity. A total of 43% of the target is melted and 4% vaporized. All of the impactor was shocked to energies sufficient for vaporization. In other runs of this model, we see that a greater fraction of the total material is melted or vaporized when: (a) impact velocity is higher; (b) the impact is less oblique; (c) the impactor is larger relative to the target; and (d) when the target body has a higher viscosity. After the impact, some of the material is ejected from the system and scatters widely from the point of impact. The material that does not escape the system clumps together at first; eventually the larger clumps coalesce into one body.

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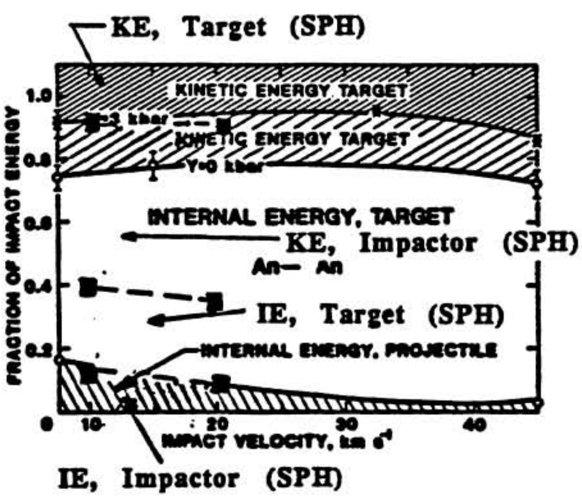
Figure 1



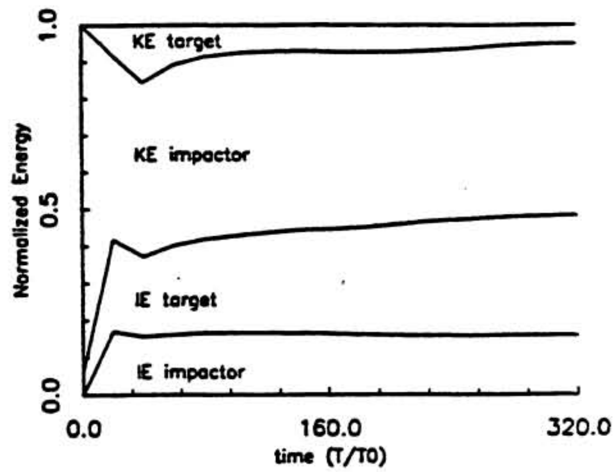


Figure 2

Figure 1. Velocity field of run described in text. Impact velocity 10 km/sec. Mass of impactor was 12% that of the target.
Figure 2. Energy budget of the run of figure 1. Initial energy is largely in the kinetic energy of the impactor; after the impact, the energy is partitioned among the target and the impactor.
Figure 3. Comparison of SPH results (squares) withhalf-space calculations. Adapted from [7].

References:

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