Experimental Studies On the Impact Properties of Water Ice

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We have continued our experimental studies on the impact of ice particles at very low velocities. These measurements have applications in the dynamics of Saturn's rings. Initially data was obtained on the coefficient of restitution for ice spheres of one radius of curvature. The type of measurements have now been expanded to include restitution data for balls with a variety of surfaces as well as sticking forces between ice particles. We have made significant improvements to this experiment, the most important being the construction of a new apparatus. Previous measurements were made using iceballs mounted on a disk pendulum which could be made to oscillate for very long periods (40-60 secs). This pendulum was placed in a styrofoam cryostat and cooled using liquid nitrogen. Although this setup was adequate for performing the first measurements, it suffered from several drawbacks. First of all the the cryostat used was not completely air-tight. Not only did this preclude the taking of measurements under vacuum conditions, but atmospheric water vapor was able to leak into the apparatus, thus making it very difficult to make measurements with iceballs that were completely free from any frost on the impact surface. Secondly, this cryostat was only able to reach temperatures of around 170°K and only for short periods of time. Measurements of the velocity were made by bouncing a laser beam off a mirror mounted on the axis of the pendulum. This reflected beam would sweep past a photocell device prior to and after each collision. The time required for the beam to sweep past the cell was a measure of the velocity of the iceball. This detector enabled us to measure the coefficient of restitution accurately down to a velocity of 0.02 - 0.05 cm/sec. Reliable data on the coefficient of restitution is needed for velocities below this.

The new apparatus consists of a smaller version of the disk pendulum and a stainless steel, double-walled cryostat. The new apparatus has proved to be a significant improvement over the old one. Measurements can now be made at temperatures near 90°K, comparable to the temperature of the environment of Saturn's rings, and with much greater temperature stability. With the recent acquisition of a diffusion pump, the iceball chamber can now be evacuated to a pressure of 10^{-5} torr. For the actual measurement of the velocity a capacitive displacement device (CDD) is now used. This device consists of a set of parallel plates mounted near the top of the disk pendulum. These plates rest between a similar set mounted on the cryostat. As the pendulum oscillates the plates on the pendulum swing between those on the cryostat. This device then measures the varying capacitance of the plate system and converts this to a voltage as a function of time which is directly related to the displacement of the pendulum. The sensitivity of the CDD enables us to obtain accurate measurements of the coefficient of restititution for velocities near 0.005 cm/sec, even for moderately short periods of oscillation of the pendulum (10-15 secs). The CDD also has an advantage over the photocell detector in its ability to measure the displacement of the pendulum as a function of time during the entire collision. This device not only improves the accuracy of our measurements but makes it possible to obtain data on the contact time of the collision.

With the old apparatus ice spheres were made by freezing water in tennis ball molds. This had the disadvantage that variations in the shape of the contact surface could not be controlled. We now use a precision aluminum mold for producing ice spheres with a radius of curvature of 2.5 cm. We also have additional molds for freezing different radii of curvature on the ice spheres. Figure 1 shows typical data on the coefficient of restitution for smooth, frost-free ice spheres with different radii of curvature (2.5, 5, 10, and 20 cm) and taken at the same temperature ($123K°$). The most obvious feature of these figures is that the dependence of the coefficient of restitution on the radius of curvature in the range of .05-1.0 cm/sec is quite weak. As one goes to higher velocities ($> 1cm/sec$) the differences in the coefficient of restitution between the various ice spheres becomes more noticeable, with spheres with the larger radius of curvature being more elastic. In the range of 0.1-1.0 cm/sec the data for all four ice spheres can be fit by either a linear or an exponential function with the exponential form providing the slightly better fit. Data taken at velocities greater than 2 cm/sec should better distinguish between the two laws, and these measurements are currently in progress. Using a function of the form $\epsilon(v) = Ce^{-\gamma v}$ to fit the data in figure 1, one finds that there is very little variation in C among the different iceballs (C$\sim$ 0.9); however there is a noticeable trend of decreasing γ with larger radius of curvature. The behavior of γ versus R, the radius of curvature is shown as an insert in figure 1. It is a linear relation of the form $\gamma(R) = 0.41 - 0.1R$. For the 5, 10, and 20 cm radii iceballs only the exponential fits to the data are shown.

A large effect on the coefficient of restitution can be caused by the condition of the contact surface before the collision. We find that a roughened contact surface or the presence of frost can cause a much larger change in the restitution measure than the geometrical effect of the radius of curvature. Figure 2 shows data taken during one run using an ice sphere that had a radius of curvature of 20 cm. Circles represent data taken while the iceball had a relatively smooth surface. Triangles represent data taken using the same ball after the cryostat had been evacuated for several minutes at a relatively high temperature (T=210$^\circ K$). This allowed the ball to sublimate and thus created a roughened surface on the ball. Crosses represent data taken after water vapor was blown across the surface of the same iceball thus allowing frost to form. An even further reduction in the coefficient of restitution is evident. At a velocity of 0.5 cm/sec the sublimated iceball was 20% more inelastic than the smooth ball at the same velocity while the frosted ball was 30% more inelastic. This is much larger than the variation in the coefficient of restitution at a given velocity between different iceballs with the same radius of curvature, which can be as large as 10%.

Work is now in progress to further quantify the effects of sublimation and frosting. We have recently completed a gas handling system that enables us to deposit carbon dioxide, methane, or ammonia on the surface of the iceball. Effects on the restitution measure with these substances present will also be examined.

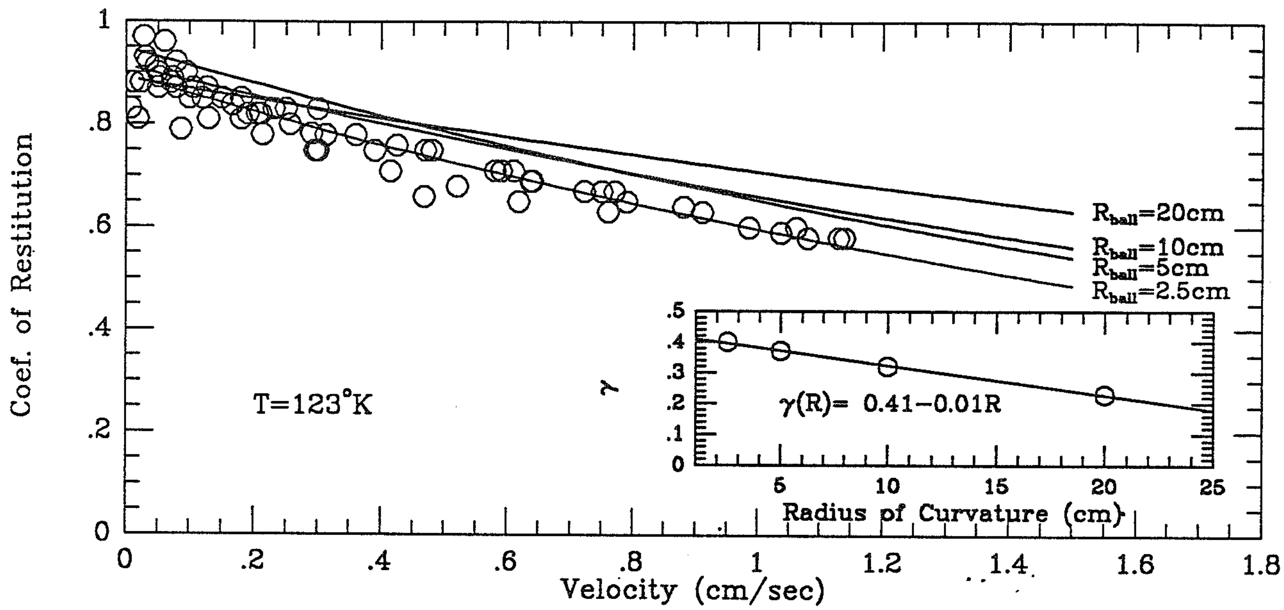

Fig. 1: Typical data taken with a smooth iceball of radius 2.5cm (circles). Lines represent exponential fits to the data of the form $\epsilon(v) = Ce^{-\gamma v}$. Fits to the data for balls with larger radii of curvature are also shown. Insert shows behavior of γ with radius of iceball.

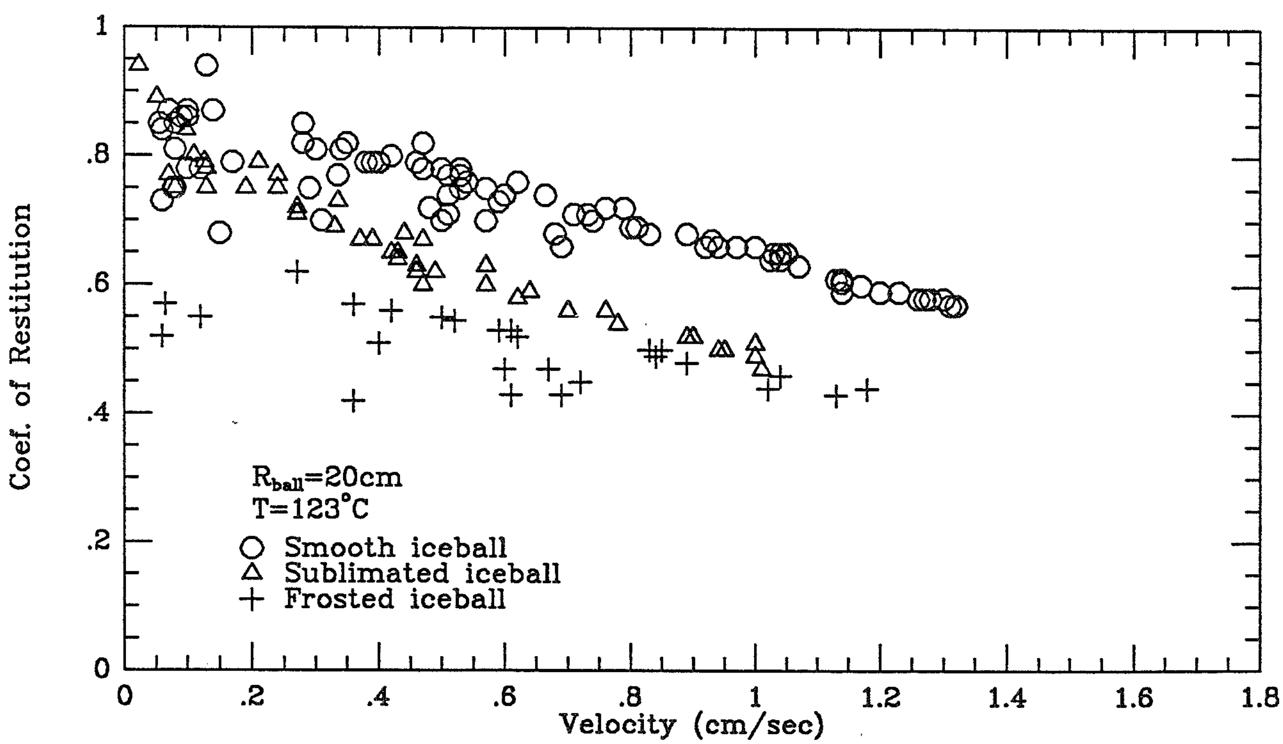

Fig. 2: Restitution data for an iceball with 20cm radius of curvature. This shows the changes in the coefficient of restitution after the ball is sublimated (triangles) and then frosted (circles).