Making Craters With Rays
Notes to Accompany The Video Clip

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This four second clip shows a glass marble being dropped into a 3 inch deep pan of flour covered with a thin, uniform layer of cocoa powder to simulate a lunar surface. The ball appears as a blur on the top edge of the film at about the 2 second mark. When the ball hits the 'lunar surface,' it creates a crater and simultaneously ejects the matter from the crater hole. This produces a set of three prominent white streaks or rays emanating from the hole, similar to what astronomers see in craters on the moon that are presumed to be produced in the more recent geological past.

This clip can also be used for some physics and geometry problems.

Speed estimation

The first possible exercise is estimating the speed of the marble (meteor, when it was in motion, meteorite afterwards) and the height from which it was dropped.

One must first create a scale for the image, which will depend on the way the video is viewed. The pan is 3 inches (7.5 cm deep) and from outer edge to outer edge it is 22cm. For ease, the ball was dropped in the approximate center of the pan. The video shows 20 frames per second and the ball takes but one frame (0.05 seconds) to go from film edge to impact.

However, the film was shot at an angle, which is somewhere between 45 and 60 degrees from the horizontal. This foreshortens the visible track of the impacting ball by a factor equal to the cosine of the angle from the horizontal. Thus the actual track length is the measured amount (coincidentally about one-half the pan size or 11cm after using a scale for your actual viewing size) divided by the cosine of the angle. The cosine of 45 degrees is .707 and for 60 degrees the value is .866 . The actual path seen is thus 15.5 to 19 cm long. One can use the average of 17.3 cm with a range of plus-minus 1.7 cm.

Since the average speed during this interval is $\Delta v/\Delta t$, this works out to be 17.3/0.05 or 346 cm per second, plus or minus 34 cm/sec. This equal the final velocity V_f at the moment of initial impact.

From what height was this ball released?

The equations needed are $V_f =$ gt (the gravitational constant g or 980 cm/sec^2 times time in seconds from the moment of release) and height = ½ g t^2 .

Using V_f from above, we get t = 0.353 seconds have elapsed from release to impact. Substituting this into the height equation we get a height of 61cm. This is about two feet high or 60 cm. However, with our uncertainty, we could have released the ball from as high as 73.6 cm or 29 inches to 18 inches. After the fact, we recreated the experiment and found it to be roughly 30 inches.

Energies

Given the Vf above, we could calculate the kinetic energy (KE) upon impact as ½ m Vf^2 and use the change in KE to find the change in Potential Energy (PE) and the height again. The values should be identical. The mass is approximately 0.75 ounces or 21 grams. The KE would thus be about 0.01 joules.

Deceleration

The ball itself is 2.0 cm in diameter. It clearly comes to rest below the surface level, though still partially visible in the hole. It can be estimated to have gone, then, only about half way down into the flour, or about 3 cm for the ball's lower edge up from the pan. The ball's center would have thus penetrated 2cm. One can use these values to calculate a deceleration value, given that it took only about 0.05 seconds to come to a stop. Acceleration would be a negative 6.92 meters per second per second, after conversions.

Determining the exact angle of the camera

The sides of the tray going away from the camera will appear shorter by the sine of the angle from the horizontal. From above all the sides would have the same length on the screen. From horizontal, the sides moving away would be so foreshortened as to have zero length. Thus, measuring the ratio of the sides moving away versus the length side to side of the tray would give us the sine of the angle of the camera above being horizontal. Using the arc-sin function would get that angle itself.

On our screen, we measured 15.5 cm for the sides lining away and 23 cm for the nearer edge. Knowing that they should be 22 cm each, and that we have about a 0.5 cm uncertainty, given the irregularity of the edges and the curved corners, we estimated a value of 43 degrees from the horizontal.