Over the Hill

Energy Transformations of a Marble Rolling on a Track

A classic carnival game involves rolling a bowling ball on a track so that as it travels away from you it goes over a small hill, into a valley, part way up a second higher hill until it stops and reverses direction, but then can't get back over the initial hill as it returns toward you, and remains in the valley.

Our small-scale version of this game uses a large marble, and a steel shelf bracket bent into the desired shape. Figure 1 below shows the entire track (the marble would begin at the left end and initially roll toward the right). Figure 2 shows a larger detail of the track and marble.

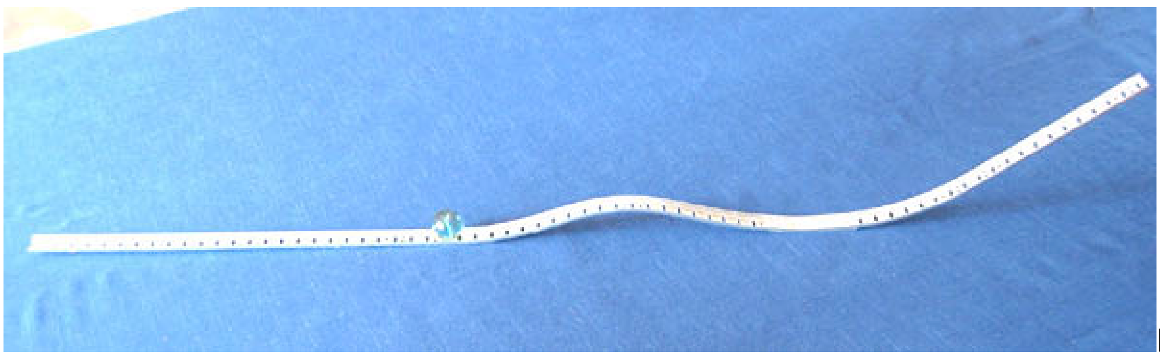
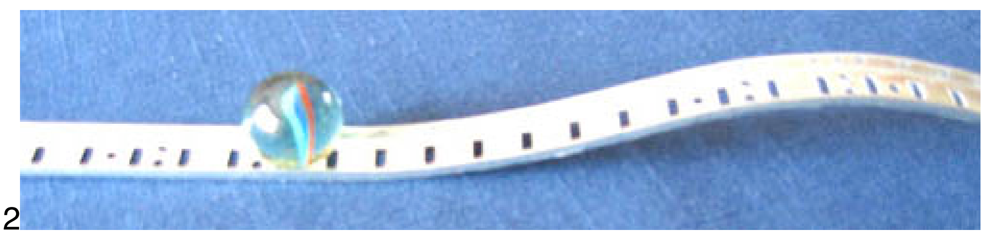


Figure 1

Figure 2



Materials

• steel shelf bracket, 3 ft ($1.17 at Home Depot at this date)

• large marble – 35 mm (1 3/8 in) diameter marbles and 25 mm (1 in) diameter marbles seem to work about the same in terms of difficulty to "win" the game – a 25 mm marble is shown above – regular small marbles won't work because they're too small to ride on the track edges

Assembly

Bend the steel shelf bracket to a profile similar to the one shown above, or design your own profile.

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To Do and Notice

Try to roll the marble so that it climbs over the small hill, but can't get back again, and is trapped in the valley. Keep track of how many times it takes to get your first success, and how many wins you get in your first ten tries.
Try another set of ten. Did you improve? Is this a game of chance or a game of skill?

Where is mechanical work being done? Where is kinetic energy greatest? Where is gravitational potential energy greatest? Where is kinetic energy least? Where is gravitational potential energy least? Is conservation of energy being obeyed in this game?

What's Going On?

This is a game of skill, not a game of chance. You will probably find that practice will improve your ability significantly. On average it is likely that it will take participants enough tries to win a prize that the game will turn a profit for the carnival proprietors. (If the prize costs less than the price of a game ticket, the profit is assured!)

This is an outstanding example of energy transformations, involving work, kinetic energy, gravitational potential energy, and heat.

You do mechanical work on the marble to get it rolling on the flat track, and this work appears as kinetic energy. As the marble climbs up the small hill, kinetic energy is transformed to gravitational potential energy, and as it goes down the hill on the other side, this process is reversed. This transformation process is then repeated as the marble climbs the second hill, comes to a stop and reverses direction part way up, and then comes back down the hill. It is repeated yet again on the small hill on the way back. Along the entire journey, friction is constantly causing kinetic energy to be transformed to heat.

If friction causes enough kinetic energy to be transformed to heat after the marble initially gets over the small hill, then the marble won't be able to get back to the top of that hill on its return. It will become trapped in the valley, losing more kinetic energy to heat each time it oscillates back and forth in the valley, until it finally comes to rest.

KE is greatest immediately after you stop doing work to get the ball rolling. Maximum gravitational potential energy could occur at either the top of the first hill, or at the ball's highest point on the second hill, depending on circumstances. Kinetic energy is least when the ball is stopped, which would be where it reverses direction on the second hill. Gravitational potential is least when the ball is at the lowest elevation, which would be on the initial flat section and at the bottom of the valley. Conservation of energy is definitely present in this device, in that at any given instant, the sum of KE, PE and heat are equal to the mechanical work done initially.

If the device was 100% efficient – that is, if there was no friction, and therefore no energy transformed to heat – then it would be impossible to trap the ball in the valley, since if the ball initially makes it over the first hill, it will make it over that hill again on the way back. But no real device is actually 100% efficient, a fact of nature expressed in the Second Law of Thermodynamics.

Going Further

Can you devise a way to determine a value for the percent efficiency of the device?

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