31.4: Newton's Cradle

Newton's cradle is a device consisting of several identical suspended steel balls hanging in a row such that adjacent balls are touching (Fig. $31.4.1$). If you pull one ball away from the end and release it, it will collide with the row of other balls, and one ball at the opposite end of the row will fly upward to almost the same height from which the original ball was released.

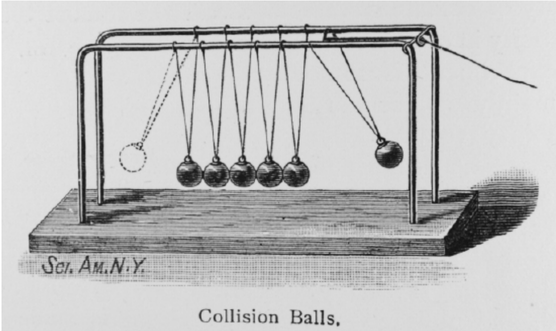

Figure 31.4.1: Newton's cradle. (Credit: Scientific American.)

It is easy to see that momentum is conserved during the collision: assuming each ball has mass m, the first ball hits the rest of the balls with speed v, and so it has momentum $p = mv$. The ball flying off of the other end after the collision will have initial speed v, so it also has momentum $p = mv$. So just before the collision of the first ball, the system has momentum $p = mv$, and has this same momentum $p = mv$ after the collision.

But momentum could also be conserved if the device sent up two balls after the collision, each with speed $v/2$. Before the collision, the momentum of the system (due to the motion of the first ball) is $p = mv$; after the collision, the momentum of the system in this case would be $p = m(v/2) + m(v/2) = mv$, and momentum is still conserved. So if momentum is conserved in either case, how does the device "know" to send up one ball, rather than two, after the collision?

The answer is that the collision between the steel balls is close to being perfectly elastic, and so kinetic energy is also conserved (not just momentum). The initial kinetic energy of the system just before the collision is equal to the kinetic energy of the first ball: $K = mv^2/2$. If one ball goes up after the collision, then the kinetic energy after the collision is also $K = mv^2/2$, and kinetic energy is conserved, as required for an elastic collision. But if two balls go up (each with speed $v/2$ to conserve momentum), then the kinetic energy just after the collision is $K = m(v/2)^2/2 + m(v/2)^2/2 = mv^2/4$, and kinetic energy would not be conserved. Therefore if one ball is raised initially (as shown in the figure), then only one ball will fly off of the other end after the collision.