A Circular Motion Activity with Hot Wheels® Rev-Ups

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Introduction

Hot Wheels® Rev-Ups[1] provides a pedagogically engaging and inexpensive culminating activity for the application of circular motion with constant speed in introductory mechanics. The introductory Rev-Up, shown in figure 1, consists of a very durable car with two strong magnets built into the front and back of the car. The track is a piece of flexible plastic with a built-in metallic strip through its center that can then be formed into a circle. By pushing the car forward several times on a flat surface it can then be placed inside the track allowing the car to move in a vertical circle. What makes this toy attractive is that the gearing system allows the car to move at a near constant speed for about 3 to 5 seconds before friction becomes appreciable and slows the car down.

Activity Outline

The goal of the activity is to estimate the contact force by the track on the car at the top of the circle, $F_{T\ top}$, and at the bottom, $F_{T\ bottom}$ while the car is in motion at a constant speed. Figure 2 shows the representation of the experiment along with the appropriate free-body diagrams. At the top of the circle the centripetal force is given by $F_c = F_{T\ top} + F_g - F_{magnetic}$ and at the bottom $F_c = F_{T\ bottom} - F_g - F_{magnetic}$ assuming toward the center of the circle is positive.

Students are given simple equipment for this activity namely a stopwatch, ruler, electronic and spring balance, and some string. My approach is to have the students work in groups of three to develop the free-body diagrams, application of the appropriate physics principles to solve the problem, and the experimental procedure with little or no teacher guidance. To aid in the development of their learning I have the groups use large whiteboards and markers to map out their solution. I have found that the use of whiteboards fosters significant collaboration among the students within the group. Prior to experimentation I check for understanding by having each group deliver a short whiteboard presentation to me explaining how they know that they are correct in their approach to solving the problem. This important step allows the teacher to confront and resolve any difficulties that might arise as the group works toward their solution.

To solve the problem outlined above and with reference to figure 2, here is what needs to be measured and calculated by the students.

$F_c = mv^2/r$: To determine the centripetal force, F_c, we begin by measuring the mass, m, with an electronic balance. The radius, r, of the track can be determined by measuring the diameter of the track and dividing by two. To calculate the speed, v, we "rev-up" the car and place it inside the track. Using a stopwatch we can measure the time for two or three revolutions when the car is moving at a near constant speed. Then the students can calculate the time, *T*, for one revolution and then calculate the speed using $v = 2\pi r/T$.

$F_g = mg$: To calculate the force due to gravity, F_g use the mass, *m*, of the car multiplied by 9.8 m/s^2

$F_{magnetic}$: This is a novel challenge for the students. Since the distance between the magnets inside the car and the metallic strip remain constant then the magnetic force will remain constant as well. One approach to measuring the magnetic force is shown in figure 3. Begin by straightening the track and placing the car flat on the track. Attach string to the car so that a spring balance can be fastened to it. Using a 2.5 N or 5 N spring balance pull up slowly on the car and note the value of the spring scale at the instant the car lifts off from the track. At this instant the normal force, F_N, will equal zero so that the force reading on the scale will equal the sum of the two forces acting down, $F_g + F_{magnetic}$. The value of $F_{magnetic}$ can then be solved for. Be prepared to engage the student groups in some Socratic dialogue to help lead them to a correct approach for measuring $F_{magnetic}$.

Using their free-body diagram and their mathematical solution the students can then calculate $F_{T\ top}$ and $F_{T\ bottom}$. The speed of the car will vary from group to group resulting in reported values for $F_{T\ top}$ between 0.5 N and 0.8 N, and $F_{T\ bottom}$ between 1.4 N and 1.7 N. Although present, we ignore frictional effects between the wheels and the track with the understanding that we are estimating $F_{T\ top}$ and $F_{T\ bottom}$. We have yet to determine a way to measure $F_{T\ top}$ and $F_{T\ bottom}$ either directly or indirectly and await a clever response to this problem.

References

1. Hot Wheels® Rev-Ups are available online at www.amazon.com or through most major department stores.

Figure 1: The Hot Wheels® Rev-Up.

Figure 3: Measuring the magnetic force on the car. At the instant the normal force is zero the reading on the spring scale equals the sum of the magnetic force and the force due to gravity.