Potential and Kinetic Energy: The Roller Coaster Lab

This lab illustrates the type of energy conversions that are experienced on a roller coaster, and as a method of enhancing the students’ understanding of that concept they will create their own roller coasters to test out their ideas.

Tips:
- In order to minimize the amount of energy loss due to friction in this lab, it is necessary to construct hills that are taut rather than floppy. *This is very important to the successful execution of this lab.* Taut hills can be made by applying a continuous upward “pull” on the top of each hill. Similarly, the initial downward ramp can avoid “floppiness” by taping the first part of it flush against the wall. Hint: Taping the structure at multiple points is very helpful.
- The roller coaster course can be structurally maintained by taping the hills and loops to other objects in the classroom, such as chairs and tables. This will help with accurate height measurements for these obstacles.

Procedure:
1. You will have 4 pieces of foam insulation. To start, tape 4 pieces of the foam insulation together.
2. Tape the beginning of the rollercoaster at around 140 cm higher than the floor.
3. Tape the slide down 40 cm away from the edge of the wall.
   (See Diagram 1 for the set-up instructions 2-4)

Effects of Dropping Height

4. Have one partner form a hill, with its peak located 1 m away horizontally from the starting point as shown in Diagram 2. Do this by pulling up on the insulation to form the peak of the hill. As one partner holds it still, have the other partner drop the marble from 60 cm vertical height. (Note: The potential energy of the marble with mass \(m [kg]\) that starts at height \(h [m]\) is equal to \(mgh\). There is no kinetic energy initially if it starts at rest.) Calculate the marble’s potential energy at this drop height and its KE at the bottom of the slope.

\[ PE = \underline{\underline{\quad}} \quad KE = \underline{\underline{\quad}} \]
Q1. If there are no energy losses due to friction, what is the maximum hill height you expect it to climb?

5. If the marble makes it over the hill, then raise the height and retry. If it does not roll over, lower the hill and retry. Repeat this process until the maximum hill height is determined. Record it in the table below.

6. Now drop the marble from 120 cm. Calculate the marble’s potential energy at this drop height and its KE at the bottom of the slope.

\[ PE = \quad KE = \]

Determine the maximum height of the hill and record it in the table below:

<table>
<thead>
<tr>
<th>Dropping Height (cm)</th>
<th>Hill Height (cm)</th>
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<tr>
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Q2. How does the increase in dropping height affect the maximum hill height?

Q3. Is your dropping height larger than the height of the hill? Why do you think this is the case?

Energy Dissipation

7. Using the same hill height as when you dropped the marble from 120 cm, stretch the hill out further from the wall by 50 centimeters (so the center of the hill is 150 centimeters from the wall). This should result in a more gradual slope of the hill up to the same height as in the previous test.

8. Observe if the marble clears the hill.
9. If it does not clear the hill, then adjust the height of the hill until the marble can clear the hill and the maximum height of the hill is determined. Record it below:

\[ \text{Maximum hill height at 150 cm separation} = \underline{\text{___________________}} \]

Q4. Is your maximum hill height at 150 cm separation larger or smaller than the maximum hill height at 100 cm separation?

Q5. Why do you think this is the case?

10. Now, tape down the insulation 90 cm away from the starting point as shown in the diagram below, but keep the hill height the same as the maximum height determined in the previous step (Note: This should give you a steeper slope):

Q6. When considering frictional dissipation, do you expect the maximum hill height to be larger or smaller than the previous step?

11. Observe if the marble clears the hill.

12. If it does not clear the hill, then adjust the height of the hill until the marble can clear the hill and the maximum height of the hill is determined. Record it below:

\[ \text{Maximum steep hill height at 150 cm separation} = \underline{\text{___________________}} \]

Another way energy is dissipated is through the flexibility of the foam, allowing the slide itself to absorb some energy as the marble rides up, and slightly pushes into, the side of the hill.

Q7. Was the maximum hill height different for the steep hill and the gradual hill?
13. Now, make a loop which, at its tallest point, is the same height as the value recorded directly above. Have a partner hold it in place. See the Diagram 4 below:

![Diagram 4](image)

14. Drop the marble from 120 cm and observe whether it completes the loop.

Q8. Does your marble complete the loop?

Q9. Describe what you saw, if the marble did not complete the loop.

15. Try dropping the marble through a loop that is small enough for the marble to get through the highest point. If it does not complete the loop, then lower the loop size until it succeeds.

Actual maximum loop height = ____________________

If an object is to continue through a vertical loop, it is not enough for it to merely reach the highest point of the loop. It must actually have a minimum non-zero velocity (it must be moving) along the track at the top point in order to stay in contact with the loop. This velocity depends on the acceleration due to gravity, $g$, and the radius of the loop, $r$:

$$v_{\text{min}} = \sqrt{gr}$$

16. Calculate the minimum velocity the marble must have to complete the loop. First calculate the radius of your loop. Measure how high your loop is and divide by 2:

Radius = ____________

Predicted minimum velocity = _______________

17. Calculate the velocity of the marble using the formula for Mechanical Energy (ME=PE+KE). Compare your answer to the one you calculated in step number 15.

$v=$ __________________
Conceptual Questions

Q10. Where is the kinetic energy greatest on the course of the roller coaster illustrated below? Where is the potential energy greatest? Label the diagram below:

Q11. If you increased the size of the marble, and therefore its mass, how would the potential and kinetic energy change?

Q12. Why is the first hill on all the roller coasters always the highest one?

Competition: Build your own rollercoaster!
Now, you will have a competition to see who can make the best roller coaster! As you know, the most fun roller coasters are those that send the riders over the highest hills. The group who can make the most number of hills with the highest combined height (add up all the heights – hills need to touch the ground in between) on their rollercoaster will win!