LAKE FOREST COLLEGE
Department of Physics

Physics 114 Experiment 8: Conservation of Mechanical Energy v2 Fall 2024

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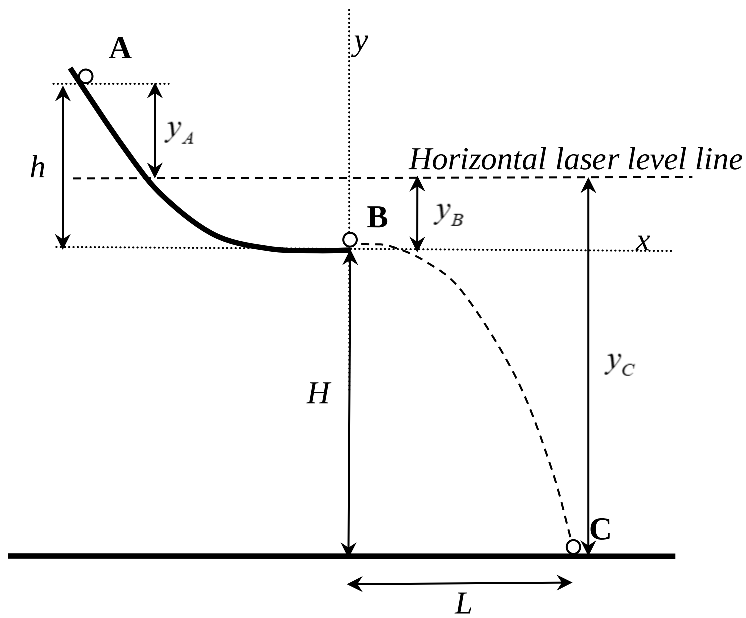
Preliminary Instructions
Create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Test the law of conservation of mechanical energy for a ball rolling down a curved track.

Pedagogical purpose of today's experiment
Study kinetic and gravitational potential energies. Review concepts of projectile motion.

Background
There are many practical situations in which Newton's Laws of Motion are difficult to apply, such as in the figure to the right where the acceleration along the track is not constant.



There is, however, a general principle, *conservation of mechanical energy*, which can be used. As long as all of the forces acting on the object (the ball in our case) are *conservative forces*, the total *mechanical energy* of the ball is conserved (constant). Gravity is an example of a conservative force. **Ideally, the work done by other forces in the system does not significantly change the mechanical energy.**

The quantities that contribute to the mechanical energy in this system are *gravitational potential energy*, which in the above coordinate system is $U = mgy$, and *kinetic energy*. The ball rolls without slipping along the track at speed *v*. The ball not only has *translational* kinetic energy, $K_{translational} = \frac{1}{2}mv^2$, but also has *rotational* kinetic energy. For this particular track and a uniform solid ball, the *total* kinetic energy of the ball is $K = \frac{9}{10}mv^2$. According to the conservation of mechanical energy, the sum of the kinetic and potential energies for the ball should be constant

$$K_A + U_A = K_B + U_B \qquad (1)$$

In this case, the ball starts at rest at point *A*, and so $K_A = 0$. We can assume that the gravitational potential energy of the ball is zero at the bottom of the track at point *B*, so $U_B = 0$.

The equation (1) becomes

$$0 + mgh = \frac{9}{10}mv_B^2 + 0 \qquad (2)$$

After the ball leaves the track, it is a projectile. The track is arranged so the ball's initial velocity is horizontal. We can measure the vertical distance (*H*) that the ball falls during its projectile motion and the horizontal distance (*L*) that it travels until it hits the ground. From these measurements we can calculate the speed at which the ball left the track:

$$v_B = L\sqrt{\frac{g}{2H}}\,. \qquad (3)$$

Procedure

Part I: Predict the speed at the bottom of the track using conservation of energy

1. Check that the end of the track is level by checking that the ball rests at the end of the track. The ball should *almost* roll off the end of the track. Level with paper shims (business cards), if necessary. Use the vertical laser level line to assure that the center of the track is in a vertical plane.

2. Set the power supply for 5 V and close the switch to energize the electromagnet. It will now hold the ball at the top of the track. Make sure that the ball is resting on the track. Have the ball holding only on the lower pole. Open the switch to release the ball. Leave the switch open (magnet off and no current) when not using the magnet to prevent overheating.

3. Because the table top and floor may not be level, use the horizontal laser level line to provide a horizontal reference height. Place the laser level so that the laser line can be seen at *A*, *B* and *C*. Measure the vertical distances y_A, y_B and y_C at the points *A*, *B* and *C* and between the laser line and the bottom of the ball. Estimate the uncertainties.

4. **Paste a picture of the setup here.** Label the important pieces.

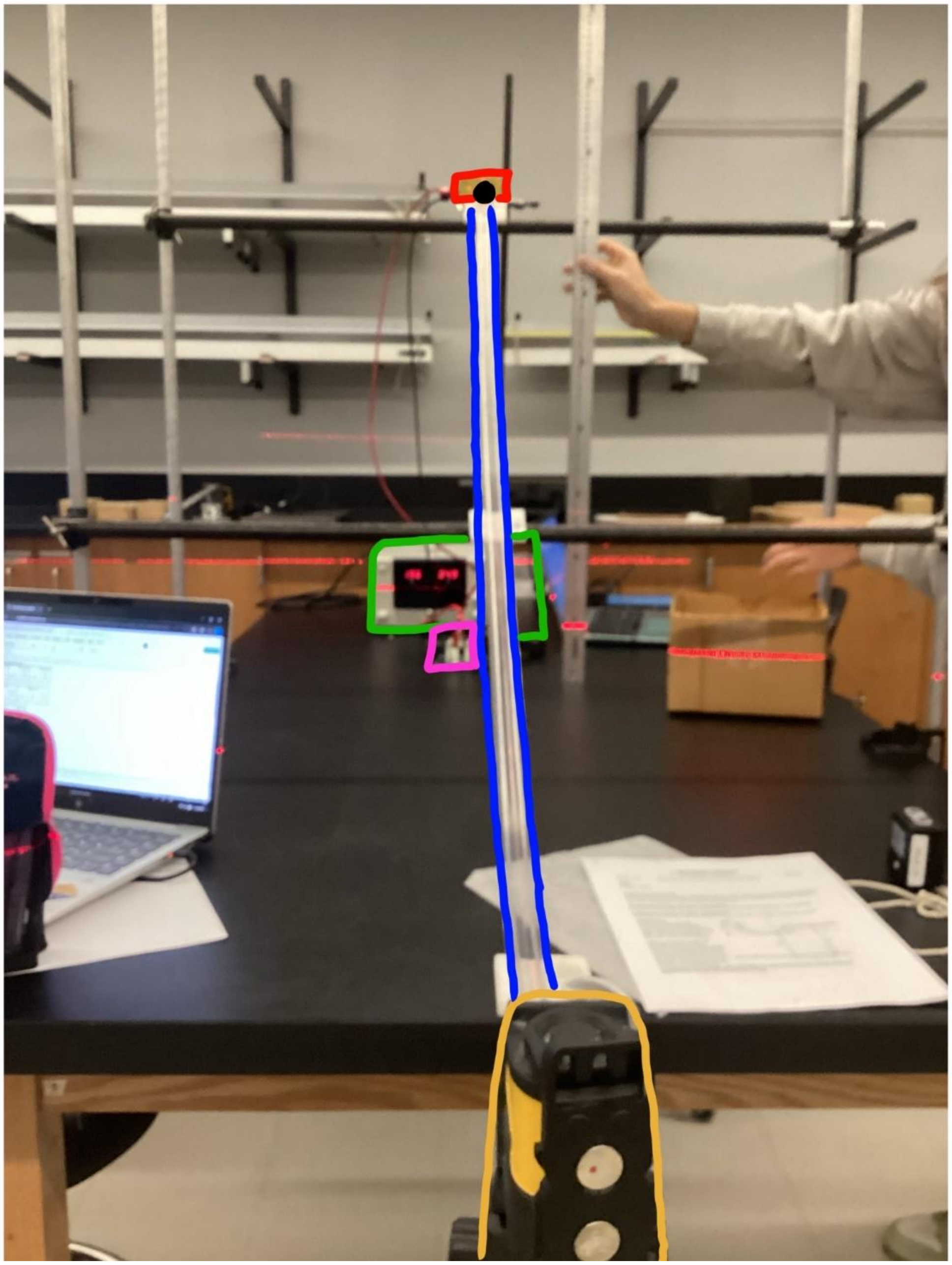


Figure 1. Apparatus. The DeWalt DW800 LaserChalk Line Laser Line Generator is outlined in yellow. The acrylic ball track is outlined in blue. The Pasco Electric Launcher SF-9296 is outlined in red and its switch is outlined in pink. The Topward DC Power Supply 33010D is outlined in green. The ball itself is marked by the black dot.

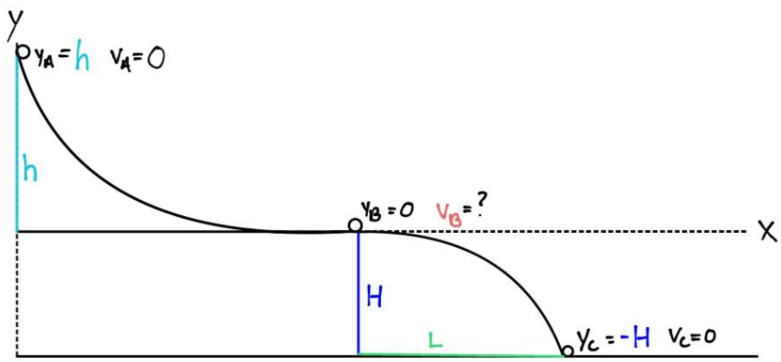
5. Derive equations for h and H from y_A, y_B and y_C. Calculate h and H. Check that these distances seem reasonable.

6. Determine the uncertainties in *h* and *H*.

7. Starting with equation (2), derive an expression for v_B. Use your measured value of *h* to calculate a prediction for v_B based on conservation of total mechanical energy.

8. Calculate the uncertainty in v_B. (Note: when a quantity is under a square root, its relative uncertainty is cut in half. For example, $\sqrt{9.00 \pm 10\%} = 3.00 \pm 5\%$.) Assume that *g* has no uncertainty.

9. **Paste a picture of the equations derived and used in steps 5-8 here.**



$$E_A = E_B$$
$$K_A + U_A = K_B + U_B$$
$$\frac{9}{10} m V_a^2 + mg y_a = \frac{9}{10} m V_B^2 + mg y_B$$
$$\frac{9}{10} m (0)^2 + mgh = \frac{9}{10} m V_B^2 + mg(0)$$
$$V_B = \sqrt{\frac{10}{9} g h}$$

$$y_f = y_i + V_y \Delta t - \frac{1}{2} a_y \Delta t^2$$
$$0 = H + 0 - \frac{1}{2} g \Delta t^2$$
$$\Delta t = \sqrt{\frac{2H}{g}}$$
$$x_f = x_i + V_x \Delta t + \frac{1}{2} a_x \Delta t^2$$
$$L = 0 + V_B \Delta t + \frac{1}{2}(0) \Delta t^2$$
$$V_B = \frac{L}{\Delta t} = L\sqrt{\frac{g}{2H}}$$

Figure 2. Equation Derivations. H, shown in dark blue, represents the distance between the lab bench and the floor while h, shown in light blue, represents the distance between the top of the track and the lab bench. L, in green, is the how the horizontal distance the ball travelled from the end of the lab bench to when it impacted the floor. The first equation shows how mechanical energy can be used to calculate velocity. This is the equation used in part one of this experiment. The second equation shows how positions can be used to calculate velocity. This is the equation used in part two of the experiment.

10. **Paste part I of your spreadsheet here.**

y_A (m)	abs. unc. in y_A (m)	y_B (m)	abs. unc. in y_B (m)	y_C (m)	abs. unc. in y_C (m)
0.665	0.001	0.09	0.001	1.002	0.001

H (m)	abs. unc. in H (m)	rel. unc. in H	h (m)	abs. unc. in h (m)	rel. unc. in h
0.912	0.002	0.22%	0.755	0.002	0.26%

g (m/s^2)	predicted v_B (m/s)	rel. unc. of v_B	abs. unc. of v_B (m/s)
9.803	2.868	0.24%	0.007

Table 1. Procedure Table

Part II: Determine the speed of the ball as it leaves the track using projectile motion

11. Derive equation (3) using the component equations for projectile motion. **Paste a picture of your derivation here.**

(See Figure 2)

12. Place a board on the floor with its center about 110 cm from the end of the track. Hold the board in place with a heavy weight. Release the ball from the top of the track and see where it lands. Reposition the middle of the board to this location.

13. Tape a sheet of white paper to the board, and place (do not tape) a piece of carbon paper on top of the paper to record where the ball lands. Set up a plumb bob and carefully draw a range reference line on the paper. This line should be perpendicular to the ball's path and labelled with its distance to the plumb bob.

14. Release the ball and record the impact point at least five times. Examine and number the impact mark after each release. **Paste a picture of the marks and reference line here.**

15. Measure the horizontal range, L, for each trial and compute the mean and standard deviation for the five trials. Use the standard deviation as the absolute uncertainty in L.

16. Calculate v_B using equation (3). Calculate the uncertainty in this measured v_B.

17. Compare the measured v_B to the value predicted in part I using the ratio test.

18. **Paste part II of your spreadsheet here.**

Part II: Projectile Motion

Trial	Horizontal Range, L (m)
1	1.073
2	1.062
3	1.065
4	1.068
5	1.065

average L (m)	st. dev. of L (m)	rel. unc. of L	measured v_B (m/s)	rel. unc. of meas. v_B	abs. unc. of meas. v_B (m/s)	ratio test btw pred. and meas. v_B
1.067	0.0042	0.39%	2.473	0.50%	0.012	20.470

Table 2. Projectile Motion Table

19. **Write an analysis here.** Comment on whether the predicted speed at the bottom of the track agrees with the measured speed. Consider possible systematic errors in the prediction and in the measurement.

The L was very consistent throughout all 5 trials. Measurement errors could lead to higher uncertainties. Leveling error, even with the laser level, may have led to more uncertainty.

20. **Write a brief conclusion here**.

Despite the predicted and measured velocities seeming very similar the ratio test shows that they disagree. This may be because the uncertainties are so small that it leave very little room for error.

This was a very fast lab so if there was a way to add some elements or do another mini experiment it might be fun. Also step 13 was very confusing, if something about how this step is measuring L then it may be clearer.

21. Adjust the formatting (pagination, margins, size of figures, etc…) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

22. Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then shut down the computers. Ensure that the laptop is plugged in.

23. Check with the lab instructor to make sure that they received your submission before you leave.