AP Physics Lab #6A: Conservation of Energy (Big Idea 4)

4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy.

4.C.1.2: The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system.

4.C.2.1: The student is able to make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass.

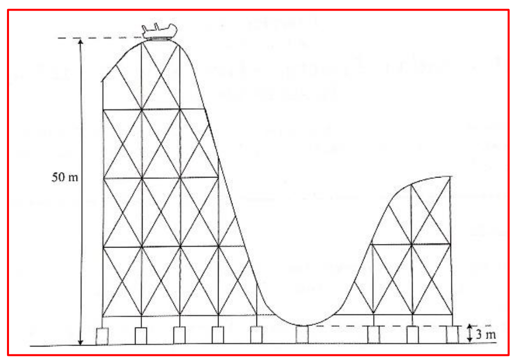
4.C.2.2: The student is able to apply the concepts of Conservation of Energy and the Work-Energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system.

In this experiment you will use the principles of energy conservation to determine the spring constant of a projectile launcher. You will then attempt to launch the projectile into a cup.

Conservation of Energy Pre-Lab:

The law of conservtion of energy states that energy is neither created nor destroyed; it can only be transferred from one form to another or be converted into work. If the work utilizes a nonconservative force, such as friction, then the energy cannot be easily recaptured since the process deforms molecules, which in turn, release heat energy. Consequently, the molecules cannot return energy to its original mechanical state as some of the energy has been dissapated in the form of heat and is no longer available. If the energy transfer utilizes conservative forces, then the form of energy can go back and forth between types. If the forms of energy involved are limited to kinetic and gravitational potential energy, the conservation be be expressed as:

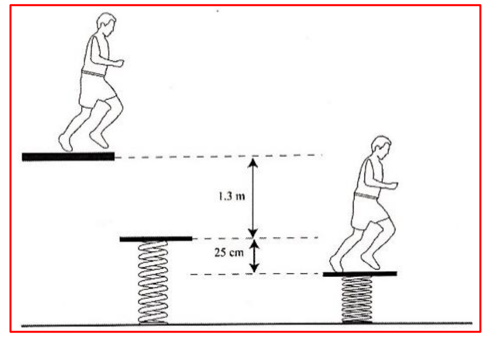
$E_{total} = mgh_i + 1/2mv_i^2 = mgh_f + 1/2mv_f^2$



P1. Suppose a 1250 kg rollercoaster is raised up the intial hill to a height of 50 m. At the top of the hill, the car has a speed of nearly zero. The car then undergoes a drop of 47 meters and continues onward. Assume that energy is consereved and that the nonconservative forces are negligible. Referring to figure 1, calculate the following: a). Total energy of the system at any given position. b). Kinetic energy at the top of the first hill. c). Gravitational energy at the top of the first hill. d). Gravitational energy 47 m below the top of the first hill. e). Kinetic energy 47 m below the top of the first hill. f). Speed 47 m below the top of the first hill. g). Maximum speed the rollercoaster car can achieve, and the position at which this occurs.

A spring has the ability to store energy. In its relaxed state, the spring has no potential energy. However, if the spring is either compressed or stretched, there is a restoring force. The further you stretch or compress the spring, the greater the energy stored in the spring. This energy is called elastic potential energy or spring potential energy, PE_s or U_s. The spring potential energy depends upon the distance the spring is stretched, x, and the spring constant, k: $PE_s = ½ kx^2$. The "k" measures the stiffness of the spring in N/m, so a stiffer spring will have a greater value for k. If the forms of energy present include spring potential, kinetic, and gravitational potential, the equation becomes: $E_{total} = mgh_i + 1/2mv_i^2 + 1/2kx_i^2 = mgh_f + 1/2mv_f^2 + 1/2kx_f^2$

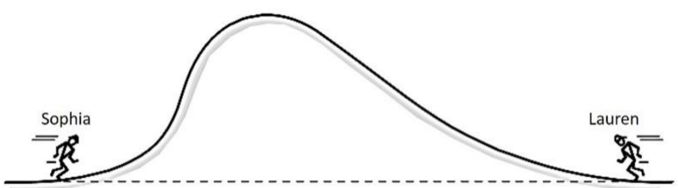
P2. A 45-kg gymnast steps off of a platform located 1.3 m above a spring board. The spring board compresses 25 cm. a). What is the spring constant of the spring board? b). If energy is conserved in this problem, explain how high the gymnast will spring upward. Assume the gymnast does not use his legs to propel himself upward.



P3. Suppose a diving board has a spring constant of 9500 N/m. If a 75-kg diver compresses the diving board a distance of 35 cm, how high will the diver be launched above the relaxed position of the diving board?

P4. The equation below results from the application of a physical principle to a physical system:
$(0.5)(12\text{ kg})(4\text{ m/s})^2 + (12\text{ kg})(9.8\text{ m/s}^2)(5\text{ m}) = (12\text{ kg})(9.8\text{ m/s}^2)(3.5\text{ m}) + (0.5)(k)(1.4\text{ m})^2$
Draw a physical situation that would result in this equation. Explain how your drawing is consistent with the equation.

P5. Sophia and Lauren decide to race up a hill that is 30 meters high. Sophia takes a path that is 60 meters long while Lauren uses a path that is 100 meters long. It takes Sophia 40 seconds since her route is steep, while Lauren runs up her path in 30 seconds. They both start from rest at the same height and stop at the top. Sophia has a weight of 700 N while Lauren has a weight of 500 N. a). Is the work that Sophia does in going up the hill greater than, less than, or the same as the work that Lauren does in going up the hill? Explain. b). Is the power generated by Sophia in going up the hill greater than, less than, or the same as the power generated by Lauren in going up the hill? Explain.

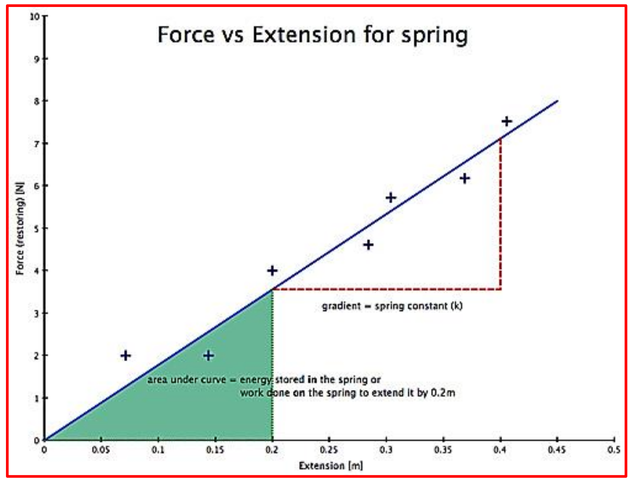


Conservation of Energy Lab:

Materials: spring ball launcher or dart gun, ruler, small balls or darts, electronic balance, force probe or spring scale, LabQuest 2 interface, Logger Pro (optional), Lab Quest App (optional), cup or box, video analysis

The spring constant may be determined experimentally by measuring the restoring force that the spring exerts on whatever is compressing or stretching it. According to Hooke's law, the restoring force, F_s, equals –kx, where x is the distance stretched/compressed. The negative sign is explained by the fact that the restoring force produced by the spring is in the opposite direction of the displacement of the spring. As the spring is compressed or stretched in one direction, it counters with a force in the opposite direction. To measure a spring constant, you can suspend known weights (forces) from one end of a spring one at a time. Each additional weight would stretch the spring a particular distance.

If you were to plot these data in terms of the force versus the extension, the best-fit line graph would look like the graph shown here. The spring constant may be determined from the graph by measuring the slope: k = F/x. In this case the spring constant is about 17.5 N/m. Take a moment to compare this value for k, to other values you may have encountered in short investigations or the pre-lab questions. Also, notice that the area under the graph is equal to the work done on the spring or the spring potential energy ($1/2kx^2$).



Lastly, you should always consider whether the spring is initially compressed or in its relaxed state. This is an important question to consider when experimentally determining the spring constant. Notice how the data in the graph to the right shows that when the spring is not extended, the restoring force equals zero. Many devices include springs that are always in a compressed or stretched condition to some extent. Consequently, the zero position has a restoring force that is <u>not</u> equal to zero. To avoid any confounding factors with your calculations, it is best to simply skip the skip the zero position in data collection and instead measure the restoring force of the first unit of displacement and then continue measuring the force and displacement data pairs. Remember that you are still measuring the spring constant by calculating the slope of the line, which should be constant.

Part 1: Measuring the Spring Constant Directly: *In this part of the lab you will determine the spring constant of a spring in a ball/dart launcher by measuring the restoring force with respect to its displacement.*

Q1. Obtain a spring launcher and use a force probe or spring scale to measure the restoring force with respect to the displacement of the spring. Create a table to summarize your data set.

Q2. Plot a graph of your data set from Q1. Take a moment to consider which variables should be on the x and y axes. Draw a best fit line.

Q3. Use your graph from Q2 to determine the spring constant for the launcher. Please show your work.

Part 2: Measuring the Spring Constant Using Energy Conservation: *In this part of the lab you will use the principles of energy conservation to determine the spring constant of a spring.*

Q4. Launch the projectile from the launcher vertically toward the ceiling. Be sure to avoid hitting obstacles such as the lights. If necessary, launch from floor height. Use a meter stick or video analysis to measure the vertical displacement of the ball. Repeat this procedure numerous times to determine the average height that the ball reached. Summarize your data in a data table.

Q5. Sketch a diagram outlining the displacement of the spring as well as the displacement of the ball. Label these displacements clearly.

Q6. Use the principles of energy conservation to calculate the spring constant of your spring.

Q7. The spring constant of the spring must be accurately known for Part 3 of this activity. How does the spring constant in Part 2 compare to the value you obtained in Part 1? There is probably a large discrepancy between the two values. The question is, which one is accurate? Please choose the accurate value and justify why you have chosen that value. What may have caused the other k value to be off?

Part 3: Predict the Landing Position of the Ball: *In this activity, you will use the spring constant to calculate the launch velocity of the ball as it leaves the launcher. You will then use this information to predict the landing position of the ball when it is launched horizontally from the edge of a table.*

Q8. Use your understanding of the principles of energy conservation to determine the launch velocity of the ball as it exits the launcher. Utilize the spring constant you determined in Parts 1 and 2.

Q9. With the launch speed of the ball known, explain how you will calculate the landing position of the ball.

Q10. Sketch and label a diagram illustrating the path of the ball from the launcher to the floor. Summarize the data needed to calculate the landing position. Calculate the landing position of the ball. You may need to review some of your notes and problems dealing with two-dimensional motion.

Q11. Now that you know where the ball is supposed to land it is time to test your prediction. Place the cup or box on the floor where you expect the ball to land. Perform numerous trials and provide a summary of your results, along with any possible factors that could be a source of error.

Please self-assess your lab report using the rubric/checklist.