

# **Proving the Law of Conservation of Energy**

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## Abstract

The purpose of this lab is to verify the law of conservation of energy. The law of conservation of energy states that in an isolated system energy cannot be gained or lost, but only transformed throughout the system, assuming there are no nonconservative forces present. If conservation of energy is indeed true, it is expected that the initial energy of a system will equal the final energy of a system. In the case of this lab, which utilizes the motion of a swinging pendulum, our goal is to prove that the energy at the start of the pendulum's motion would equal the energy at the end of the pendulum's motion. First, we calculated the theoretical acceleration of the pendulum, using the fact that  $E_{\text{initial}}=E_{\text{final}}$  (where E is energy). This told us what the velocity of the pendulum was supposed to be at the bottom of its swing. We then compared this value to the velocity determined experimentally using a photogate timer. The two values were equal, with a small percent error of 0.2% for the first trial and 0.7% error for the second trial. Thus, it was proven, within a small percent error, that the energy in the system was conserved.

## Introduction & Discussion

The concept of energy is one of the most important topics in science and engineering. This is because every physical process that occurs in the Universe involves energy and energy transfers or transformations. For example, we use energy concepts to liftoff airplanes and propel rockets. We perhaps inadvertently experience a transfer of energy whenever we watch television, listen to the radio, or blow-dry our hair. It is also important to note that energy can be neither created nor destroyed, but only transferred from one source to another. This concept, known as the conservation of energy, is the basis for this laboratory. Our goal is to verify the law of conservation of energy by proving that in a particular system, in this case, the motion of a pendulum, that energy is conserved, that is, as long as no outside forces act on the pendulum, that the energy in the pendulum system cannot be lost or gained (Serwey).

The idea of energy can be traced to Galileo in the 17<sup>th</sup> century. He noticed that when a weight is lifted with a pulley, the force applied multiplied by the distance through which that force must be applied (a value which we today call work) remains constant even though either factor may vary. This concept, called vis viva, was also shown to be directly proportional to the product of the mass and the square of the velocity. Later, in the 19<sup>th</sup> century, the term energy was applied to the concept of vis viva. Today, we may recognize Galileo's findings by the formula  $W=\Delta KE$ , where work (W) is equal to the change in kinetic energy (KE). Since kinetic energy equals one half the product of the mass and the

square of the velocity ( $\frac{1}{2} mv^2$ ), it can be seen that Galileo was correct when he claimed that work is proportional to kinetic energy (energy conversion).

In this lab, we will be dealing with two types of energy: kinetic and potential. Kinetic energy represents the energy associated with moving particles. It is defined as one half the product of the mass and the square of the velocity:

$$KE = \frac{1}{2} mv^2 \quad \text{where KE is kinetic energy, m is mass, and v is velocity.}$$

Potential energy refers to the stored energy in a system, which is dependent on the relative position of the system. There are many different types of potential energy, but in this lab we will be dealing with gravitational potential energy. This concept can be explained through an example of two balls of equal mass. If Ball 1 was raised ten centimeters above the ground, and Ball 2 was raised fifty centimeters above the ground, Ball 2 would have a greater gravitational potential energy because its ability to become kinetic energy is greater. This can be seen in the equation for gravitational potential energy:

$$PE = mgh \quad \text{where PE is potential energy, m is the mass of the object, g is defined acceleration due to gravity at } 9.8 \text{ m/s}^2, \text{ and h is the object's height with respect to a chosen reference point.}$$

It can be seen then that an object's potential energy is directly proportional to its height, thus explaining why Ball 2, raised to a greater height, also has the greater potential energy.

In this lab, we studied the motion of a swinging pendulum. Our goal is to prove the initial energy of the pendulum would equal the final energy of the pendulum:

$$E_{\text{initial}} = E_{\text{final}}$$

The pendulum will experience two kinds of energy both at the beginning and end of its motion: kinetic and potential. Therefore we can conclude that the potential and kinetic energy of the pendulum initially will equal the potential and kinetic energy of the pendulum finally:

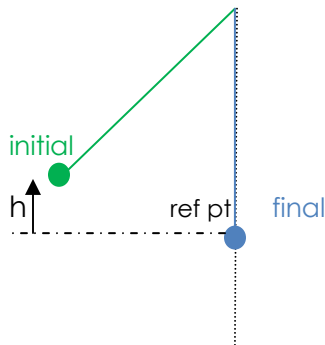
$$PE_i + KE_i = PE_f + KE_f \quad \text{where PE is potential energy, KE is kinetic energy and the subscripts i imply initial energy and f imply final energy.}$$

Any energy lost due to air resistance or friction has been neglected, therefore we assume that all there are no nonconservative forces acting on the pendulum, where nonconservative forces are defined as forces acting within a system that cause a change in the overall energy of the system.

The motion of our pendulum begins at rest from the top of the swing. The

pendulum was then allowed to fall and drop until it reached its natural position at the bottom of the swing, as shown:

Figure 1



Because the pendulum begins at rest, the initial kinetic energy of the system goes to zero. Because the reference point for the system was set to be at the bottom of the pendulum's swing, the final potential energy of the system also goes to zero, because it has no height related to it. Thus, we are left with the total energy in the system as:

$$PE_i = KE_f$$

If we substitute in our equations for potential and kinetic energy, as shown above, we can see that:

$$mgh = \frac{1}{2} mv^2$$

Solving for velocity gives us:

$$v = \sqrt{2gh}$$

Using this equation for velocity, the theoretical velocity for the pendulum could be calculated, as shown in the calculation page on Appendix B. This value was compared to the velocity determined by the photogate. Within a small percent error, it can be seen that the theoretical acceleration equals the experimental acceleration. Therefore it can be concluded that the acceleration determined in lab completes the equation for energy, and thus the pendulum obeys the law of conservation of energy.

## Procedure

Materials: Pasco Scientific Xplorer GLX PS-2002 data recorder, Pasco Scientific PS-2159 Digital Adapter, photogate timer, support rod, clamp, string, meter stick, pendulum, triple beam balance

1. Using triple beam balance, find the mass of pendulum and record it
2. Set up support rod and clamp and attach string
3. Attach pendulum to string so that the center of mass of the pendulum lies 20 cm above the ground, make adjustments in string length if necessary
4. Set up photogate timer so that the pendulum is free to swing back and forth through the middle. See Appendix C for illustrations
5. Via the digital adapter, connect the photogate timer with the data recorder
6. Data recorder should be arranged so that it reads velocity as an object passes through photogate; refer to instruction manual if needed
7. Pull the pendulum back to 40 cm from tabletop. Use meter stick to measure the height from the object's center of mass.
8. Ensure that the pendulum is pulled back straight, with a firm tension in the string
9. Let go of the pendulum so that it swings through the photogate timer; catch the pendulum on the other side so that it does not swing back through
10. The data recorder will have measured the velocity at the bottom of the pendulum's motion for one swing.
11. Record this data and record the velocities of several more trials; average them
12. Knowing that the initial potential energy of the system must be equal to the final energy of the system, substitute all values into the equation:  
$$mgh = \frac{1}{2} mv^2$$
13. The equality of the two values proves conservation of energy

## Results

We are attempting to prove the conservation of energy in this lab. Below are two tables of data collected in the lab. One is labeled 20 cm, and the other 10 cm.

Table 1:

Trial 1- 20 cm	Trial 2- 10 cm	
1.99	1.43	This means that for the one marked 20 cm, we swung the pendulum from 20 cm higher than the midpoint of itself as it was hanging. We did the same for the 10 cm one except only 10 cm higher than the midpoint.
1.99	1.4	
1.98	1.39	
1.99	1.43	
1.96	1.41	
2	1.4	

The values are the velocities in meters per second (m/s) that the photo gate timer recorded as the pendulum passed through it at the very bottom of its swing. So these velocities are recorded as how fast the pendulum was traveling when it reached the bottom of its first swing. For example, the first time we swung the pendulum through the photo gate the velocity was 1.99 m/s. For our experimental data, we are going to take the average of each of the trials by themselves. So the first trial would be 1.985 m/s as the data we will use to compare to the theoretical data. The second trial would be 1.41 for the data we will use to compare to our theoretical data. The trends that we wanted in our data were that they were as close to each other as we could get. For the most part this turned out good. They all seemed to be relatively close meaning that we had fairly constant data.

## Summary

The purpose of this lab was to prove the conservation of energy law to be true. This was done by measuring the velocity of a pendulum swung through a data recorder and comparing that speed to theoretical data. To see exactly what was done to do this, refer back to the procedure on page five.

For our experimental data we got two different velocities. One velocity is from when we swung the pendulum from 20 cm above its midpoint as it was hanging and the other 10 cm above. We did six trials on each of the heights to ensure we got good data. Then we averaged each set of data from its specific height. For trial-1, we got 1.985 m/s as the velocity of the pendulum at the bottom of its swing, and for trial-2, we got 1.41 for the velocity at the bottom of its swing. The theoretical data is found by using the method in the Calculations page on page seven. These velocities are: for Trial 1- 1.98 m/s, and for Trial 2- 1.4 m/s.

We then used the method in the calculations page on page seven to find

the percent error, we get that the percent of error for trial 1 was 0.2% error and for trial 2 was 0.7% error. This means that we proved the conservation of energy law within a very close range. We needed to be within a 5% error. Therefore we conclude that our purpose for this lab was fulfilled.

We think that the sources of error for this lab may have been the air resistance. We knew that the air resistance would not have enough of an effect on the results to take the percent error outside of 5%, but it could have slowed our pendulum down just a tad, which would have caused the error to be about what it is now. We could have also messed up our velocity by the release of the pendulum. We let it go at a certain measurement with our hands. There could have been enough friction between the pendulum and our fingers to cause the pendulum to drop at inconsistent heights which would have caused our velocities to be inconsistent. The only way to prevent this is if we would have used some sort of device to release at the same height every time.

## Appendix A: Works Cited

Energy conversion. (2008). In *Enclopaedia Britannica*. Retrieved 22, 2008, from Encylopaedia Britannica Online: <<http://www.britannica.com/eb/article-45913>>.

Serwey, R.A. (2004). *Physics for Scientists and Engineers Sixth Edition*. Belmont, CA. Thomson Brooks/Cole.

Sturgeon, K.R. (2004). *PHYS 106: General Physics Laboratory Manual*. Danville: DACC Graphics.

## Appendix B: Calculations

Since the data recorder gave us the velocities for our experimental data, we just have to average the six data times that we collected in the experiment to give a good average velocity. This is an example of how to do this for Trial 1:

$1.99 + 1.99 + 1.98 + 1.99 + 1.96 + 2.0 = 11.91$      $11.91/6 = 1.985 \text{ m/s}$  You use the same method for the second trail. This number comes out to be 1.41.

Next we have to calculate the experimental data, using the equation  $E_{\text{initial}} = E_{\text{final}}$ , as shown in the introduction. This equation, also known as conservation of energy, can be used assuming there are no non-conservative forces acting on the system, such as friction and air resistance. The g in the below equation stands for gravity. Since we did this experiment on earth, we can assume the gravity to be  $9.8 \text{ m/s}^2$ . The h in the equation below stands for height. We set our reference point to the center point of the pendulum, so for trial one which is the trial we are using for this example would be .2 m for h. For the second trial you would use .1 m. Those are the only two variables that we need to find the answer for our equation. The V for the answer is the velocity of the pendulum when it reaches a

height of 0 when it gets to the bottom of its swing when we set our reference point at the center point of the pendulum. So the equation is:

$$\sqrt{2gh} = V$$

The numbers for the variables are given in the above paragraph. When the numbers are plugged in from trial one the equation becomes:

$$\sqrt{2(9.8 \text{ m/s}^2)(.2\text{m})} = V$$

V= 1.98 m/s is the theoretical velocity for trial 1.

Trial 2 is done by using the same method and you get 1.4 m/s.

The next and last step in calculating is to find the percent of error for each trial. See below for an example calculation of percent error. Remember, we want this to be under 5% to verify the conservation of energy law.

The equation to find percent of error is:

$$\frac{(\text{Experimental}) - (\text{theoretical})}{\text{Theoretical}} * 100\% = \% \text{ error}$$

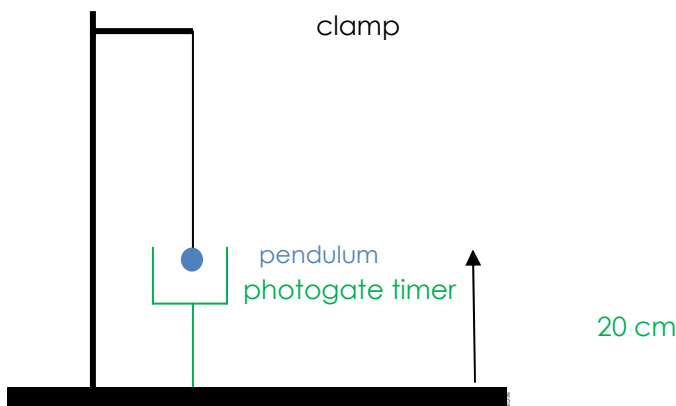
So we plug our numbers from trial 1 for an example calculation.

$$\frac{(1.985) - (1.98)}{1.98} * 100\% = 0.2\%$$

So you can see that we proved the conservation of energy law for this trial. The percent error for trial 2 is 0.7%, which means that we proved it once again.

## Appendix C: Setup Diagram

Figure 2: Setup Diagram



## Appendix D: Handwritten Data (To be Attached)