Experiment #9 The Ballistic Pendulum

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Objective:

The object of this experiment is to use the data gathered to prove that within a closed system, momentum before equals momentum after. Additionally, it should prove that kinetic and potential energy equal each other at the appropriate points.

Theory:

Since PB equals PA within a closed system, we expect that the momentum before and after, and the Ek and Ep energies of the system should equal each other. Although, due to outside forces, the system is not perfect, so that energy and momentum will actually be lost instead of conserved. However assuming this loss is very small allows us to still use the calculations and relationships between energy (both Ek and Ep) and momentum, to calculate further information such as velocity. (And with a little more effort, force and time as well.)

Methods:

The experiment was conducted using a ballistic pendulum, a spring scale and the triple-beam balance. The balance was used to measure the mass of the ball, whilst the spring scale was used to measure both the mass and weight of the pendulum bob. This was done by attaching the spring scale to the bob, and recording the data observed when the bob was completely horizontal. (A ruler was also used to measure the length of the pendulum.)

The ballistic pendulum had two parts. The first part was a small cannon, onto the end of which the bob was placed. The lever was cocked, and when ready, it fired the ball. The second part was the pendulum, consisting of a pendulum aligned with a protractor, and attached to a ball cage with a depressor to catch the ball at the end. Once the cannon was fired, the ball cage snagged the ball, and the combined ball and bob rose to a certain angle as measure by the protractor.

Data:

The tabletop on which the apparatus was sitting was slanted so all angles are one degree off, that is, what is reported is the original/observed angle minus one.

Run 1 $\theta =$	30.0°	$\pm$ 0.25
Run 2 $\theta =$	31.0°	$\pm$ 0.25
Run 3 $\theta =$	30.0°	$\pm$ 0.25
Run 4 $\theta =$	30.0°	$\pm$ 0.25
Run 5 $\theta =$	29.0°	$\pm$ 0.25
Run 6 $\theta =$	30.0°	$\pm$ 0.25
Run 7 $\theta =$	30.0°	$\pm$ 0.25
Run 8 $\theta =$	29.5°	$\pm$ 0.25
Run 9 $\theta =$	29.0°	$\pm$ 0.25
Run 10 $\theta =$	29.5°	$\pm$ 0.25

Average Angle θ =	29.5°	$\pm$ 0.25

Mass of ball = 0.065kg
Mass of pendulum bob = 0.2kg
Length of Pendulum = 30cm
Height reached at average angle = 3.9cm

Calculations:

The height the ball reaches is found by l - lcos0:
30cm - (30cm)cos29.5 = 3.89cm

The initial velocity of the ball by itself is:
$v0 = m_1 + M_2/m_1 (\sqrt{2gh})$
$v0 = 0.065kg + 0.2kg/0.065kg (\sqrt{2g(0.039m)} = 3.57m/s$

Plugging this values into $1/2mv^2$ yields:
Ek = 0.4142 J

Ep is the potential energy of the ball and pendulum given by: Mgh
$(m_1 + m_2)gh$, (0.065kg + 0.2kg)g(0.039cm) = 0.1014J

The Velocity of the combined masses is obtained by using momentum, PB = PA
$M_{ball}V_{ball}B/(M_{pen+ball}) = V_A$, V_A equals 0.815m/s

Plugging this value into $1/2mv^2$ yields: 0.1014 J

Therefore we see that the kinetic energy just after the collision of the ball and pendulum equals the potential energy at the top of the pendulum's swing.

Using ΔP = mv, and the fact that PB = PA, we find that:
$(m_1)(vB)$ = PB, (0.065kg)(3.57m/s) = 0.23205 Ns, and
$(m_1 + M_2)$ = PA = 0.231875 Ns

Results:

The kinetic energy just after the collision of the ball and pendulum equals the potential energy at the top of the pendulum's swing.

Additionally, the momentum before is very close to the momentum after, but factors such as friction slightly lesson the momentum afterward.

Ek before = 0.414J
Ek after = 0.1014J

Initial Velocity of the ball = 3.57m/s
Velocity of the ball+the pendulum = 0.875m/s

PB = 0.23205 Ns
PA = 0.231875 Ns

Error analysis:

The first type of error was introduced because the tabletop was uneven, causing tilting, and therefore adjusted for the angle. Secondly, the angles were not that easy to read, and it was possible to over or underestimate the half angles. Thirdly, the ball didn't quite strike the bob in the same place every time, thus varying the angle slightly, and fourthly, friction between the pendulum and its axis changed the angle readings slightly, as well as initial adjustments to make sure the pendulum hung at zero.

The uncertainty for the angles was $\pm$ 0.25
The mass had error about $\pm$ 0.1, and the height about $\pm$ 0.02, so The error range for initial velocity was then $\pm$ 0.28.

Using this error range for velocity, the uncertainty for Ek becomes $\pm$ 0.00078

For final velocity, the error range is $\pm$ 0.14
Given these ranges, the ranges for PB and PA are as follows:
$\pm$ 0.0028, and $\pm$ 0.0028

These error ranges were obtained by working the uncertainties through the problem.

Conclusions:

True to our predictions, there was a slight loss (through conversion to heat) of energy and therefore of momentum. This is due mostly to friction, the friction between the pendulum and the axis on which it rotates. Other sources of friction, such as the friction between the ball and the rod from which it is launched and the friction between the ball and the pendulum bob as it enters the cage, are negligible.

We are here ignoring air resistance because given the speed and mass and shape of the ball, air resistance is small enough to be negligible. Despite the fact that a few sources of friction and air resistance can be virtually ignored, there are are other factors that could have affected the experiment such as: the accuracy at which the angles are reported, whether the ball hits the pendulum dead on, and whether the pendulum is accurately reset to 0 degrees.