Trampolines and Conservation of Energy

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Physics 211-02

Purpose:

The purpose of our trampoline experiment was to find a correlation between the percentage of energy loss with each bounce and the mass of each ball. From this, we were able to find the height at which the ball rebounds after being dropped. By the law of conservation of energy, we know that if mechanical energy is conserved, anything dropped at a certain height should bounce back to the exact height from which it was dropped. This can be explained by a simple transfer of energy: when the ball is held above the spring surface it has a certain amount of gravitational potential energy and, upon release, that gravitational potential energy is transferred to kinetic energy at a proportional rate to keep the total mechanical energy of the system constant. Once it comes in contact with the spring surface, that kinetic energy will be transformed into spring potential energy at the same rate to keep the total mechanical energy constant. However, based on previous knowledge we knew that in actuality the ball would not bounce back to the same height it was initially dropped from. This occurs because energy is transferred from spring potential energy to other forms of energy (such as acoustic, chemical, or thermal energy). The total energy is still conserved but this loss of our system's energy to other forms of energy results in a smaller bounce of the ball. We ultimately want to know how the mass of the each ball affects the energy it loses and how this relates to its rebound height (Ohanian and Markert, 2007).

Equations and Theory:

In our project, we investigated the concept of energy and more specifically the transfer and conservation of energy. Trampolines are unique objects in that when objects are dropped on their surface, the object rises to almost the height it was dropped from. This sparked our interest in the concept of conservation of energy. When an object is held above the trampoline at a certain height, it has an amount of gravitational potential energy that can be found from the equation:

$$E_{pg}=ma_{g}y \qquad (1)$$

where m is the mass of the object, a_g is the acceleration of freefall, and y is the height at which the object is held. As soon as the object is released and begins falling, some of the potential energy is transformed to kinetic energy, which can be calculated using the equation

$$E_{k}=½mv^{2} \qquad (2)$$

where m is the object's mass and v is the speed at which it is traveling at that instant of time. In order to find out the average velocity of the object immediately before it comes in contact with the trampoline, we used the equation

$$v= (y_{2}-y_{1}) / (t_{2}-t_{1}) \qquad (3)$$

where y_2 and y_1 represent the final and initial positions in the vertical direction, respectively, over the amount of time taken for that change. For all of our calculations, a is the acceleration of gravity (because that is the only direction of motion for every object dropped). While the object falls, the amount of potential energy decreases at the same rate as the kinetic energy increases. At every instant of time the sum of the gravitational potential energy and the kinetic energy adds up to a constant value known as the total mechanical energy of the system. Once the object comes in contact with the trampoline, however, that kinetic energy transforms to another type of potential energy – the potential energy of springs. This value is defined as

$$E_{ps}=½ks^{2} \qquad (4)$$

where k is the spring constant and s is the distance the spring is stretched from its equilibrium position. According to the law of conservation of mechanical energy, if mechanical energy is conserved, these three forms of energy within the system always add up to a certain number that stays constant, represented by the equation

$$E_{pg} + E_k + E_{ps} = \text{constant} \qquad (5)$$

Since mechanical energy can be calculated before the ball hits the trampoline, we were able to calculate the spring constant of the trampoline (Laws, 2004).

Procedures:

Our experiment required the use of the following:

1. A small trampoline
2. A video camera
3. A meter stick
4. A spring scale and electronic balance
5. 3 balls of varying masses
6. Video Point software

The trampoline was placed on a level surface away from any outside influences that could affect the validity of our data (such as wind). The video camera was set up to record the trampoline and the space directly above it (approximately two meters). A meter stick was held over the center of the trampoline, recorded, and removed. This allowed for us to collect data in meters rather than in pixels when utilizing Video Point.

The following three balls were used:

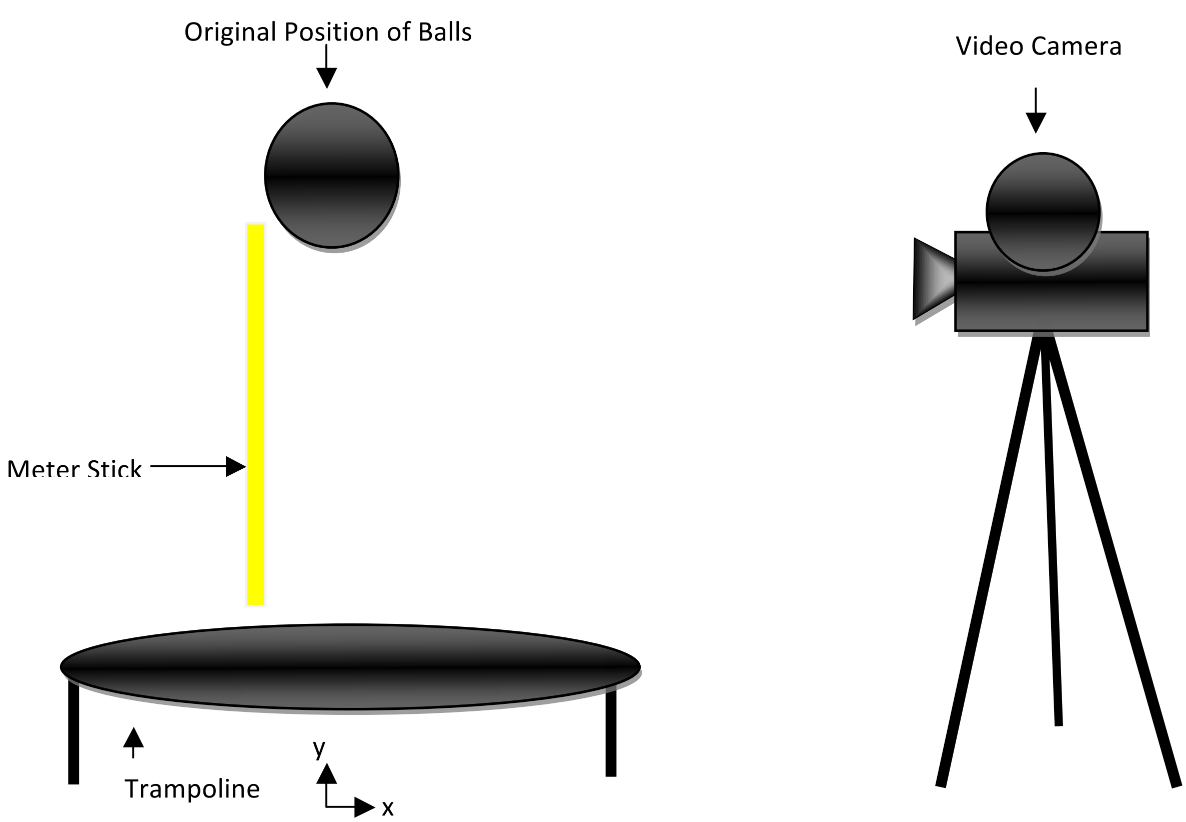
1. A medicine ball, 4.0 kg
2. A bowling ball, 7.27 kg
3. A basketball, 0.5833 kg

The mass of each ball was determined through the use of the spring scale or electronic balance. Each ball was held one meter over the center of the trampoline and dropped twice. Each drop was recorded using the video camera. During the first drops, the balls were only allowed to bounce once. They were caught at their highest point just before they began to drop again. During the second drops, the balls were allowed to bounce until they came to a stop.

The video footage was converted to QuickTime format for use in the Video Point software. The vertical *y*-position of each ball was recorded for analysis.

Below is a diagram of the setup of the experiment.

Figure 1



Data Tables:

Table 1: The time vs. height data for the bowling ball during the first, second, and third bounces. Measurements were taken as soon as it left contact with the trampoline until it fell back down.

First Bounce	
time (s)	y (m)
0.000	0.092
0.040	0.227
0.070	0.350
0.100	0.446
0.140	0.554
0.170	0.635
0.200	0.712
0.240	0.773
0.270	0.808
0.300	0.846
0.340	0.889
0.370	0.912
0.400	0.923
0.440	0.927
0.470	0.915
0.500	0.896
0.540	0.869
0.570	0.827
0.600	0.777
0.640	0.715
0.670	0.642
0.700	0.554
0.740	0.439
0.770	0.304
0.800	0.165
0.840	0.019

Second Bounce	
time (s)	y (m)
0.000	0.081
0.030	0.192
0.070	0.315
0.100	0.412
0.130	0.492
0.170	0.569
0.200	0.635
0.230	0.677
0.270	0.704
0.300	0.723
0.330	0.735
0.370	0.742
0.400	0.742
0.430	0.719
0.470	0.700
0.500	0.662
0.530	0.619
0.570	0.554
0.600	0.485
0.630	0.381
0.670	0.296
0.700	0.177
0.730	0.065

Third Bounce	
time (s)	y (m)
0.000	0.058
0.030	0.158
0.060	0.246
0.100	0.331
0.130	0.415
0.160	0.469
0.200	0.519
0.230	0.554
0.260	0.585
0.300	0.592
0.330	0.604
0.370	0.608
0.400	0.592
0.430	0.573
0.470	0.535
0.500	0.496
0.530	0.439
0.570	0.377
0.600	0.292
0.630	0.204
0.670	0.085

Table 2: The time vs. height data for the basketball during the first, second, and third bounces. Measurements were taken as soon as it left contact with the trampoline until it fell back down.

First Bounce	
time (s)	y (m)
0.000	0.076
0.040	0.191
0.070	0.282
0.100	0.366
0.140	0.450
0.170	0.519
0.200	0.576
0.240	0.607
0.270	0.641
0.300	0.664
0.340	0.679
0.370	0.683
0.400	0.672
0.440	0.657
0.470	0.630
0.500	0.592
0.540	0.534
0.570	0.473
0.600	0.405
0.640	0.302
0.670	0.195
0.700	0.084

Second Bounce	
time (s)	y (m)
0.000	0.061
0.040	0.149
0.070	0.229
0.100	0.290
0.140	0.347
0.170	0.397
0.200	0.428
0.240	0.443
0.270	0.458
0.300	0.458
0.340	0.443
0.370	0.424
0.400	0.393
0.440	0.351
0.470	0.290
0.500	0.218
0.540	0.137
0.570	0.046

Third Bounce	
time (s)	y (m)
0.000	0.061
0.030	0.126
0.070	0.195
0.100	0.237
0.130	0.271
0.170	0.294
0.200	0.313
0.230	0.313
0.270	0.305
0.300	0.286
0.330	0.252
0.370	0.210
0.400	0.157
0.430	0.092
0.470	0.027

Table 3: The time vs. height data for the medicine ball during the first, second, and third bounces. Measurements were taken as soon as it left contact with the trampoline until it fell back down.

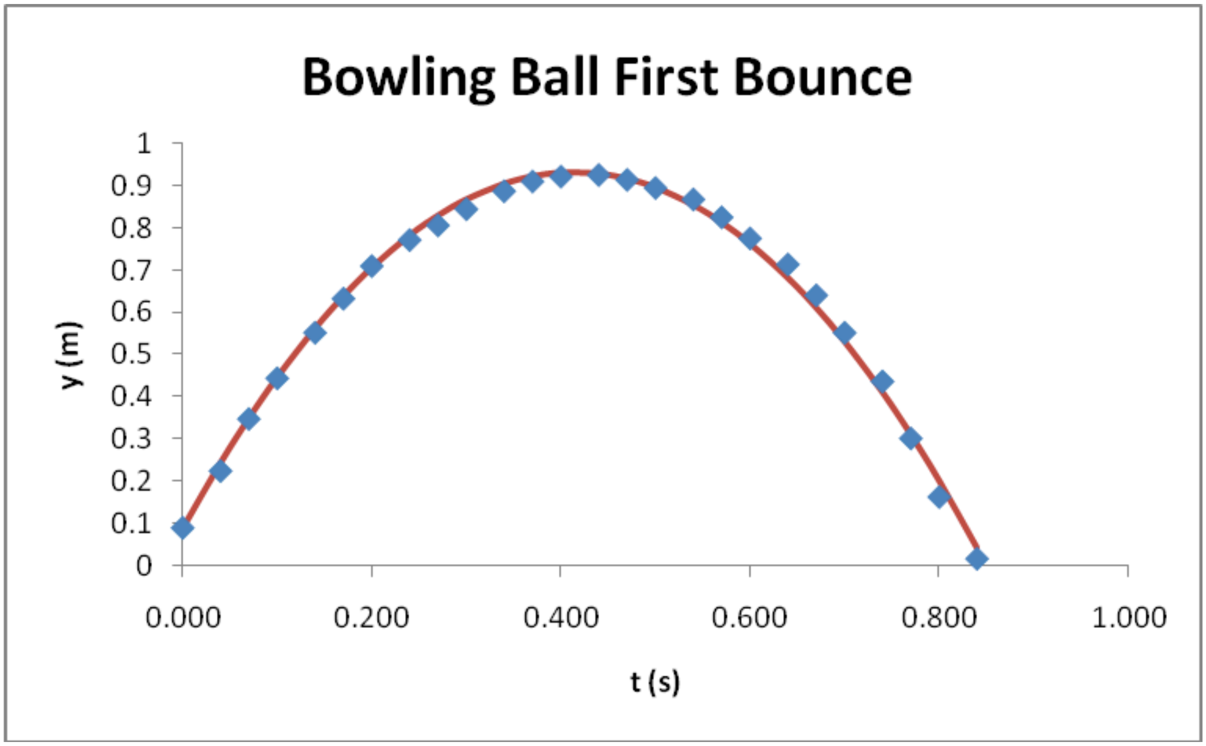
First Bounce	
time (s)	y (m)
0.000	0.023
0.033	0.152
0.067	0.262
0.100	0.369
0.133	0.453
0.167	0.525
0.200	0.612
0.233	0.665
0.267	0.707
0.300	0.749
0.333	0.768
0.367	0.783
0.402	0.795
0.435	0.791
0.467	0.780
0.502	0.761
0.535	0.722
0.568	0.673
0.602	0.608
0.635	0.551
0.668	0.464
0.702	0.357
0.735	0.255
0.768	0.133

Second Bounce	
time (s)	y (m)
0.000	0.008
0.033	0.118
0.066	0.224
0.100	0.304
0.133	0.380
0.166	0.445
0.200	0.491
0.233	0.536
0.266	0.563
0.300	0.586
0.333	0.597
0.366	0.601
0.400	0.589
0.433	0.567
0.466	0.532
0.500	0.498
0.533	0.434
0.566	0.373
0.600	0.297
0.633	0.194
0.666	0.095

Third Bounce	
time (s)	y (m)
0.000	0.015
0.033	0.099
0.066	0.179
0.100	0.251
0.133	0.293
0.166	0.346
0.200	0.388
0.233	0.407
0.266	0.418
0.300	0.418
0.333	0.414
0.366	0.392
0.400	0.369
0.435	0.327
0.468	0.270
0.501	0.209
0.535	0.141
0.568	0.046

Results:

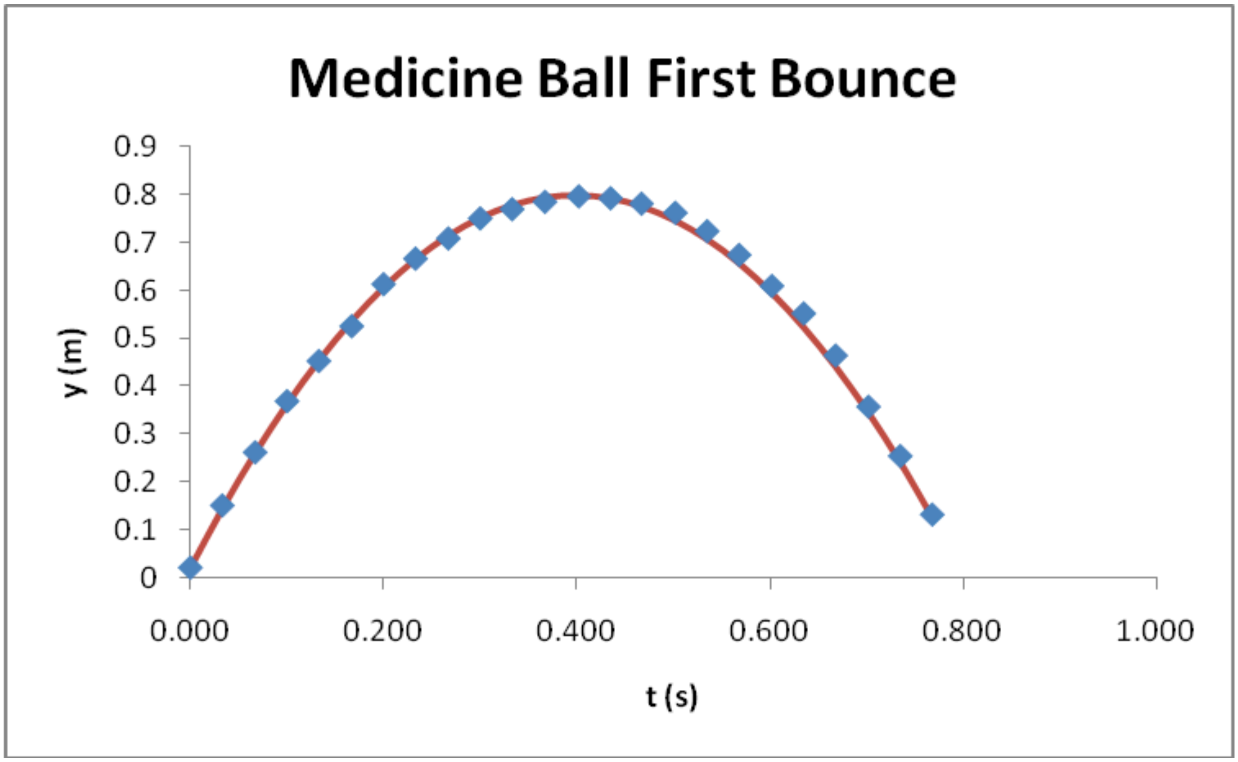
The following graphs are position versus time graphs representing data taken immediately after each ball began to “bounce back” after the original drop. They are no longer in contact with the trampoline.



Graph 1: The position vs. time graph for the bowling ball's first bounce off of the trampoline. The subsequent bounces had similar shapes.

Table 4: The modeled equations for each of the position vs. time graphs of each bounce

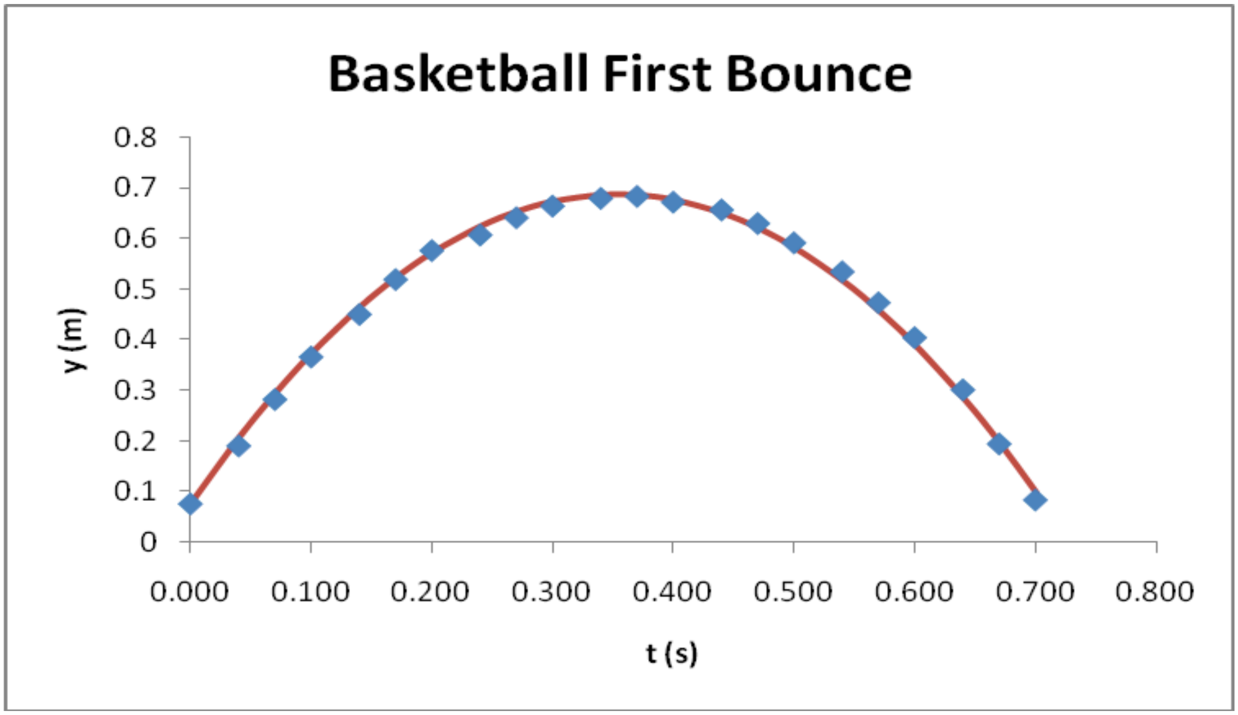
First Bounce: 0.076m + 3.46m/s*t -4.9m/s^2*t^2
Second Bounce: 0.061m + 2.78m/s*t -4.9m/s^2*t^2
Third Bounce: 0.061m + 2.22m/s*t -4.9m/s^2*t^2



Graph 2: The position vs. time graph for the medicine ball's first bounce off of the trampoline. The subsequent bounces had similar shapes.

Table 5: The modeled equations for each of the position vs. time graphs of each bounce

First Bounce: $0.023m + 3.9m/s*t - 4.9m/s^2*t^2$
Second Bounce: $0.008m + 3.4m/s*t - 4.9m/s^2*t^2$
Third Bounce: $0.015m + 2.84m/s*t - 4.9m/s^2*t^2$



Graph 3: The position vs. time graph for the basketball's first bounce off of the trampoline. The subsequent bounces had similar shapes.

Table 6: The modeled equations for each of the position vs. time graphs of each bounce.

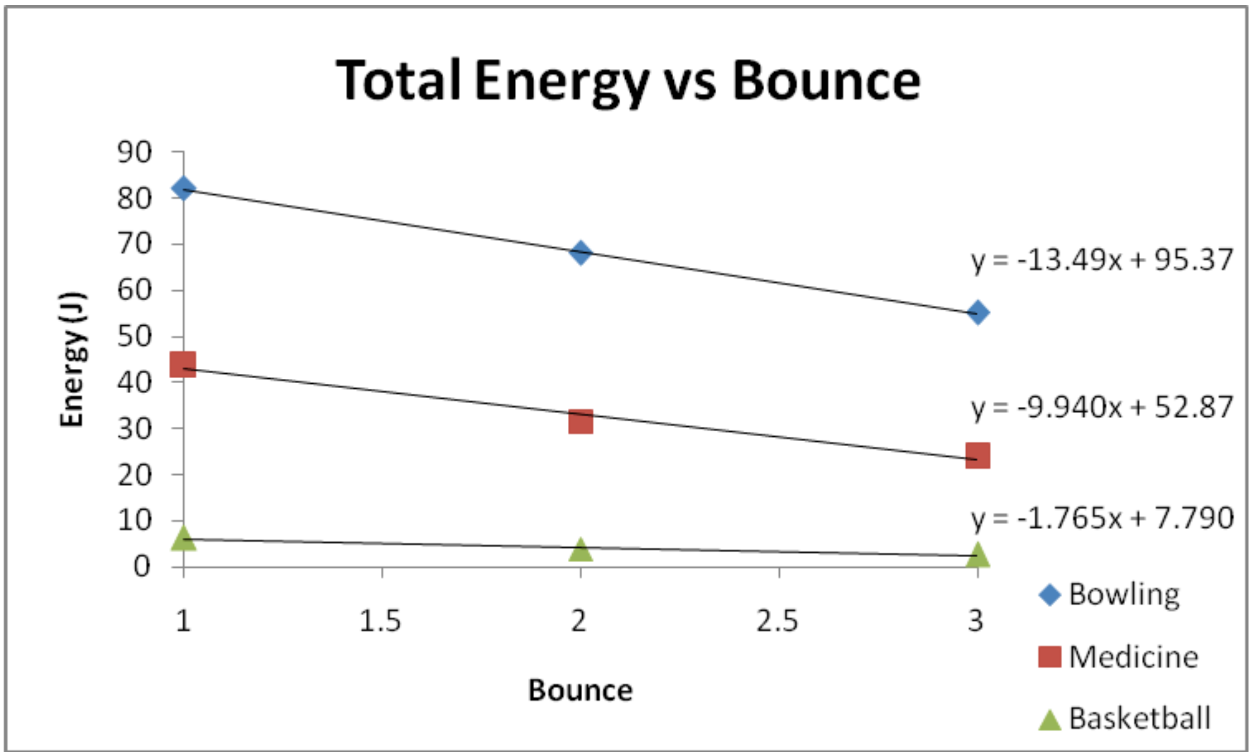
First Bounce: 0.076m + 3.46m/s*t -4.9m/s^2*t^2
Second Bounce: 0.061m + 2.78m/s*t -4.9m/s^2*t^2
Third Bounce: 0.061m + 2.22m/s*t -4.9m/s^2*t^2

The following tables and graphs show the progressive loss of energy for each ball observed during the previous collision of the ball with the trampoline. These plots show linear correlations between the drop in energy and the number of bounces. This is what we expected because some of the potential, kinetic, and spring energy of the ball/trampoline system is transformed into other forms of energy with each bounce, so the total energy of the ball, and therefore the height, decreases with each bounce.

Table 7:

Total Energy in system after each bounce (J)

	Bowling	Medicine	Basketball
E_{To}	82.068	43.665	6.186
E_{T1}	67.992	31.527	3.941
E_{T2}	55.074	23.785	2.655
E_{T3}	43.885	16.403	1.775



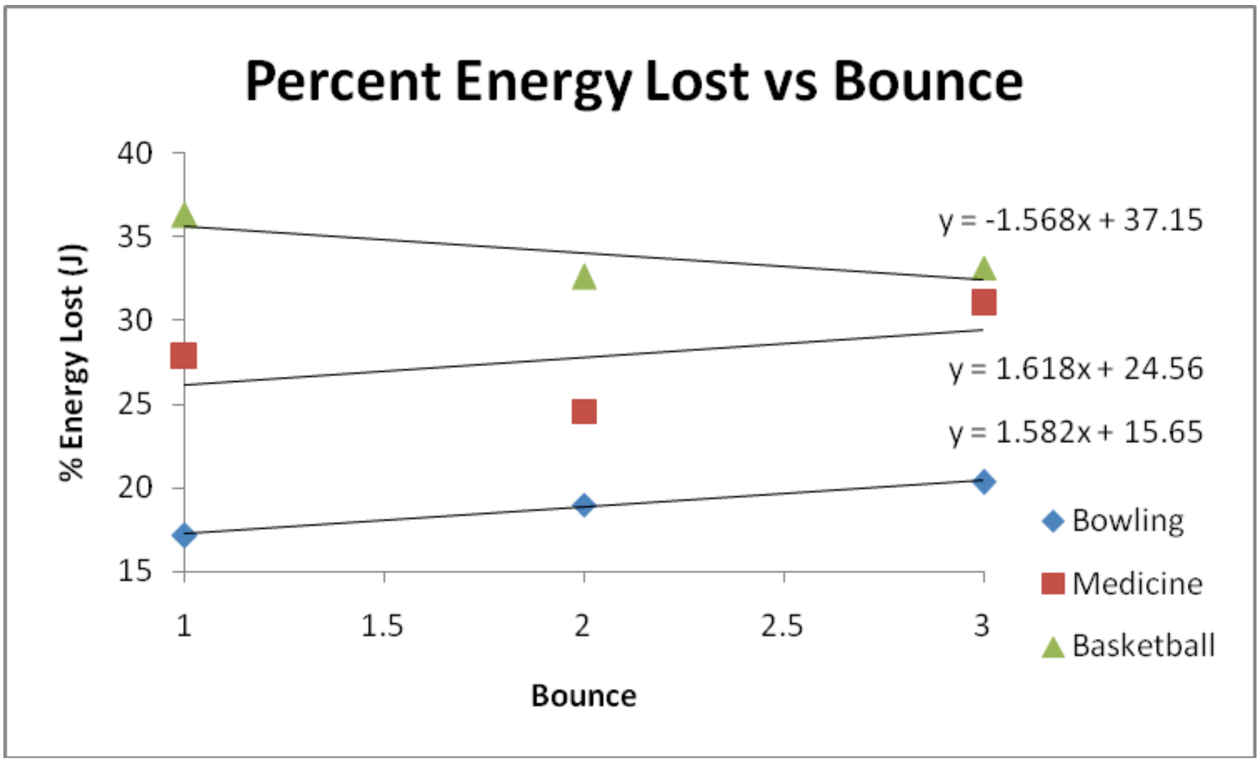
Graph 4: Total energy remaining in the ball/trampoline system for each ball after each bounce.

The following tables and graphs show the percent of energy lost in the system after each collision of the ball with the trampoline. This shows us that for each of the three balls, the energy lost seems to increase with each bounce. The plots show that the correlation is linear. The energy drops by relatively the same amount after each collision of the ball with the trampoline.

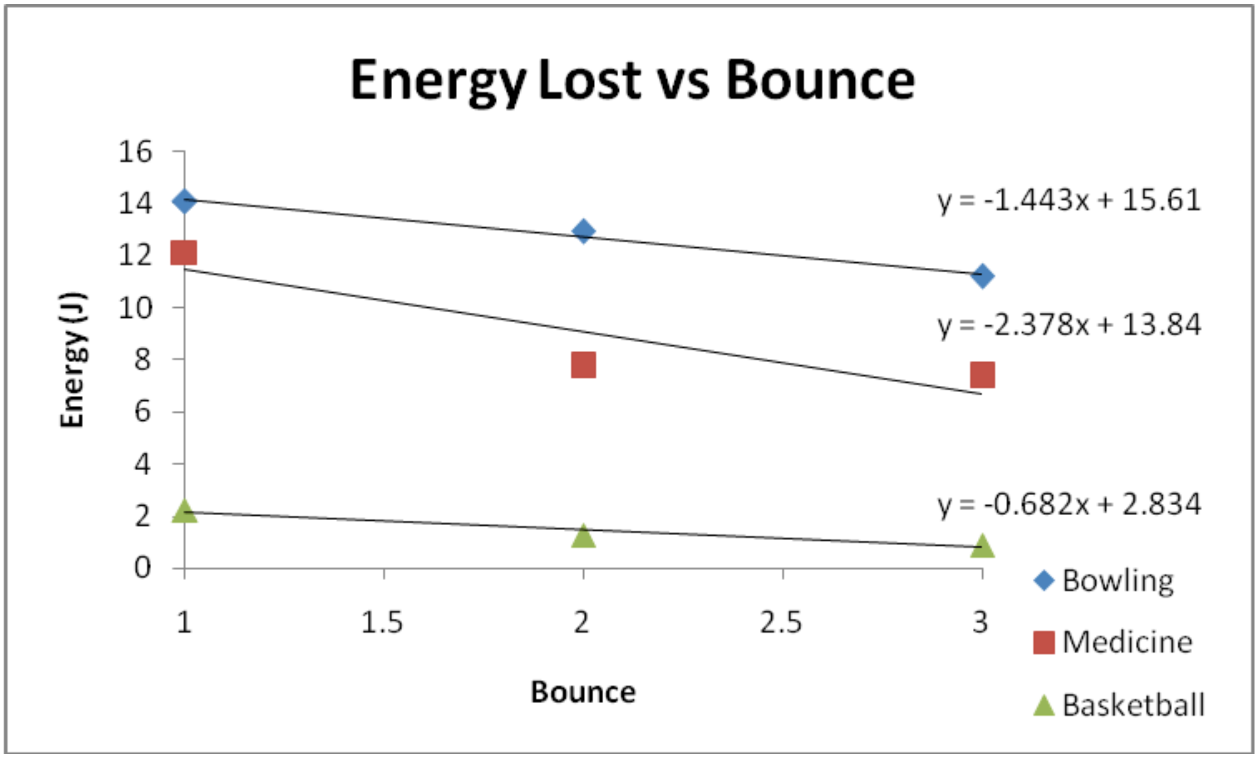
Table 8:

% Energy lost after each bounce

	Bowling	Medicine	Basketball
Drop	0%	0%	0%
1st bounce	17.152	27.799	36.284
2nd bounce	18.999	24.558	32.624
3rd bounce	20.317	31.036	33.147



Graph 5: A graphical representation of the previous table, showing that the percentage of energy lost has a linear relationship with the number of bounces.



Graph 6: Total energy lost in the system after each bounce.

<u>Sample Calculations:</u>

Medicine Ball:

$v = (y_2\text{-}y_1)/ (t_2\text{-}t_1)$ Equation (3)

(1.034m $\hat{y}$ - 1.065m $\hat{y}$) / (.200s - .134s) = -.0470m/s $\hat{y}$

$E_{pg} = ma_g y$ Equation (1)

(4.0kg)*(9.8m/s^2)*(1.053m) = 41.2776 J

$E_k = ½mv^2$ Equation (2)

½*(4.0kg)*(-.0470m/s)^2 = .441 J

Percent Energy remaining in the system $(\%E_{remain}) = (E_k + E_{pg}) / (E_{k\ initial} + E_{pg\ initial}) * 100\%$

(31.527 J / 43.665 J) * 100% = 72.2%

Estimated height of the next bounce $(y_{approx}) = \%E_{remain} * (E_{k\ initial} + E_{pg\ initial}) / (mass * a_g)$

72.2% * (42.2776 J) / (4.0kg * 9.8 m/s^2) = 0.779 m

Discussion:

After collecting and analyzing our data, we have learned to distinguish between what is useful information and what is extraneous or impertinent to our purpose. We thought that the position vs. time graphs for each of the balls would be useful in many ways to help us determine the energy loss and the height of rebound for each of the balls, but they only tell us two essential values: the height the ball bounces and the velocity of the ball as it leaves the trampoline. We did not end up using the modeled velocities but instead found the velocity at each moment in time using equation 3 in order to calculate the loss in energy and the height of the rebound. By equation 5 we know that the total mechanical energy before the ball drop can be calculated by just the ball's gravitational potential energy. Because the ball was dropped at rest and was not in contact with the spring then there is no kinetic energy and no potential spring energy. The height of the ball given in the position vs. time graph enabled us to calculate the energy loss after each bounce. We were also able to find the approximate height of the bounce knowing the initial mechanical energy of the ball. The approximate height is given by the equation:

$$(y_{approx}) = \%E_{remain} * (E_{k\ initial} + E_{pg\ initial}) / (mass * a_g) \qquad (6)$$

We found the spring constant to be of no real importance as far as how it affects the prediction of the height of the bounce. This fact is contrary to our original assumption that the spring constant will determine the height of the rebound. The effect that the trampoline did have on the ball was that the collision resulted in a loss of mechanical energy from the ball. The motion was observed elsewhere (e.g. in the motion of the trampoline after the collision) and the loss of energy would have been much quicker or more influential on the bounce had the trampoline not been present and the balls had been bounced on a harder surface such as the floor.

Finding the mechanical energy loss after each bounce was the key to reaching our purpose. Our purpose, again, was to find a correlation between the percentage loss of energy of each ball and the mass of that ball. We discovered to our surprise that the basketball which has the least mass had the greatest percentage energy loss as opposed to the bowling ball which has the greatest mass and the least percent energy loss.

This led us to our final conclusion. Referring back to the law of conservation of energy, we know that if mechanical energy is conserved throughout the system then each ball should rebound to the same height (one meter in this case) from which the ball was initially dropped. Since more mass resulted in the least energy loss, this must mean that the ball with the most mass (the bowling ball) will rebound closest to one meter. The basketball, which had the least amount of mass and the most energy lost, will rebound farthest from one meter. We had a preconception that the bowling ball would lose the most energy due to its large mass and would barely rebound on the trampoline but we were wrong. We are now convinced that more mass on a trampoline means greater rebound and vice versa.

As with every experiment, we had uncertainties that are impossible to totally eliminate and to reduce the uncertainties we needed to be meticulous with the set up of our experiment. If we can obtain good data then our experiment will be more valuable to our findings. Our first major source of uncertainty stemmed from our videos that were recorded for each ball used in the experiment. The videos that were recorded turned out to be less than ideal which made data collection harder and thus added uncertainties to our data. For example, the number of frames that Video Point allowed us to collect during the compression of the trampoline is not sufficient enough to find the true maximum displacement in the trampoline though this value is not pertinent to our focus. We had to accept what was given to us in the Video Point. However, in order to reduce the uncertainties that came with our blurred Video Points, we collected many data points so that eventually our data points became more uniform and showed the shape of the graph.

To make analyzing data easier for us, we set the origin using the Video Point software at the top of the trampoline. The problem with this is that the Video Point is blurry and dark we had to guess where the top of the trampoline begins which will result in too high or too low y values. Since our experiment's main focus is on the law of conservation of energy, we need to be careful to reduce any external factors that may take energy away from the bounce that would affect our system's energy loss. During this experiment, we noticed that the trampoline moved as the ball rises. This suggested that energy was lost during the trampoline's movement and we were not expecting additional energy loss.

If we could do the experiment again, we would be more stringent on reducing our uncertainties to obtain the best data available. This would include better lighting and clearer Video Points and gluing the trampoline down to the ground. In our case, we collected adequate data to enable us to see the correlation between the percentage of energy loss in each ball and the ball's mass. From our experiment, we could find the number of rebounds each ball could go before coming to a stop or the ideal ball mass that would rebound closest to one meter. We could also change the drop height and repeat the experiment to see if there are any changes in energy loss and rebound height.

We would also explore beyond the scope of round objects with mass on a trampoline. We want to know if surface area of the object or if the material the object is made of would make a difference in energy loss. We really want to test the validity of our conclusion with us as part of the experiment. If each of us were dropped 5 meters above a trampoline, which one of us would achieve the greatest bounce? We are guessing Colby would win but we could be fooling ourselves! Though we discovered many new answers to energy loss and trampolines, we also take from this experiment more questions about objects and their interaction with trampolines.

References

Ohanian, H.C., & Markert, J.T. (2007). *Physics for engineers and scientists* (3rd ed.), New York: Norton.

Laws, P.W. (2004). *The physics suite: workshop physics activity guide* (2nd ed.) Hoboken, N.J.: Wiley.