PHYS 101 Lab Project

Conservation of Energy in the Conversion of Elastic Potential to Kinetic and Kinetic to Gravitational Potential Energies and in Elastic Collisions

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Part A Conversion of Elastic Potential Energy to Kinetic Energy:

Objective:

This part of the experiment aims to inspect whether the elastic potential energy of the spring can be fully converted to kinetic energy. Kinetic energies will be determined with different starting elastic potential energies. Finally, the error will be found by comparing the experimental result and theoretical result. Observing that elastic potential energy is conserved as a result of this part will be accomplished.

Theory:

1) $U_{\mathrm{el}} = 1/2 * k * x^2$ [2]

2) $U_{\mathrm{el}} \sim x^2$

3) $K = 1/2 * m * v^2$ [2]

4) $1/2 * k * x^2 = 1/2 * m * v^2$ [2]

(k, x = force constant and the compression amount of spring respectively; v, m = velocity, and mass of the object respectively)

The elastic potential energy stored in a string depends on the force constant and the spring compression (formula 1). The formula shows that the energy stored in the spring is directly proportional to the square of the compression amount of the spring (formula 2). Therefore, by changing the compression amount of the spring, even if the force coefficient is not known, one can infer that the elastic potential energy will change proportionally.

Kinetic energy depends on the mass and speed of the object (formula 3). If the object's mass is known, finding its velocity after the spring was released is sufficient to find its kinetic energy. The velocity can be calculated by periodically measuring the object's positions after being launched on a friction-reduced surface.

The ratio of kinetic and elastic potential energies can be examined by changing the elastic potential energy using different compression amounts of spring. Suppose the ratio is directly proportional with the 4th formula. In that case, the energy is conserved while the elastic potential energy is transformed into kinetic energy.

Setup of Experiment:

Equipment List:

1) Air Table
2) Puck
3) Spark Timer
4) Spring
5) Carbon Paper
6) 30 Cm Ruler
7) Scientific Calculator
8) Balance

Procedure and Data:

1) First, measure the weight of the puck.
2) Then fix the spring on one side of the air table such that it makes 45 degree angle with air table.
3) Compress the spring at certain intervals and mark them on carbon paper by writing the amount of compressions in centimeters.
4) Using all the marked points in order, throw the puck on carbon paper with the power of the spring.
5) Measure the displacements of the puck by using traces marked at certain time intervals on carbon paper and save the values in the row which intersects the column of corresponding compression amount in table 1.1.
6) Plot x vs. t graph at plot 1.1 using table 1.1 and find all average velocities. Record them to table 1.2.

7) Using formulas 2 and 3, find the kinetic energies (using found velocities) and elastic potential energies (using compression lengths) for all compression amounts. Record these data to corresponding columns of table 1.2. (If the elastic potential energy due to compression by 1 cm is called 1E, the energy gaining by 2 cm compression can be called 4E and so on.)

8) Plot K vs. U_{el} graph at plot 1.2 using table 1.2 and draw the best possible line.

9) Determine the best possible line of graph 1.2 indicates formula 4 (Linear equation) and calculate the error percentage of the experimental and theoretical result.

Table 1.1

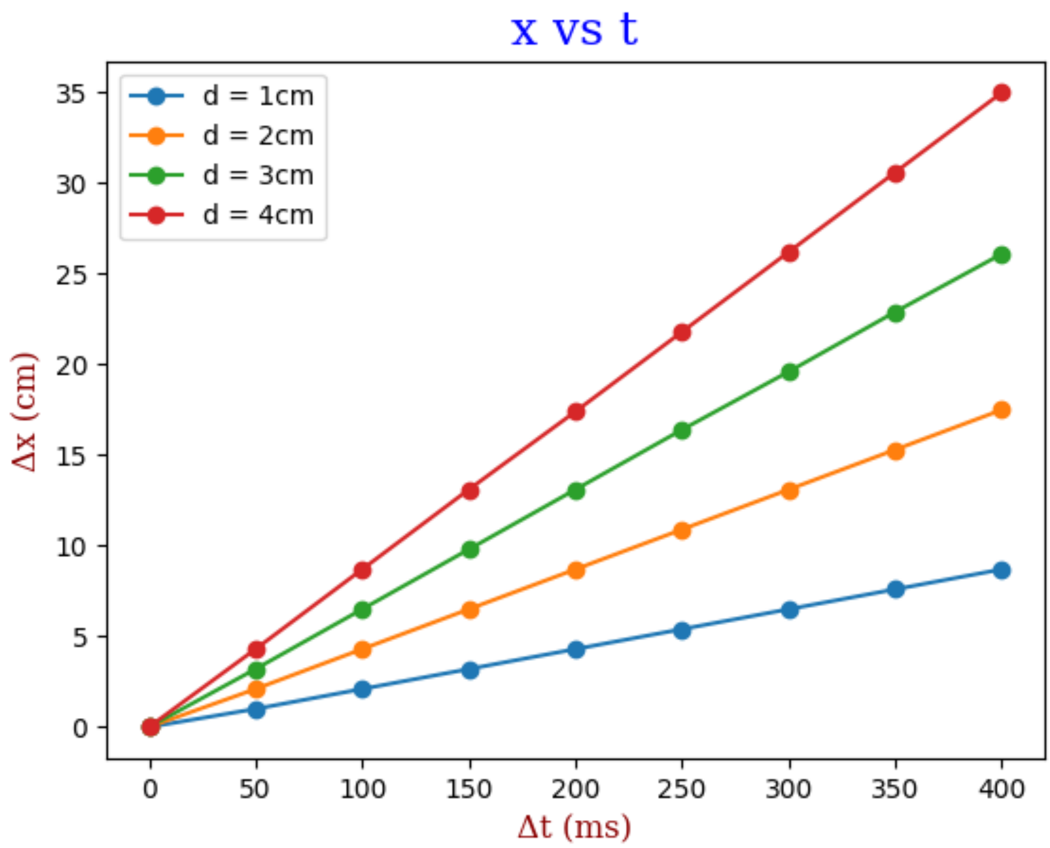
$\Delta \boldsymbol{x}_d$ = displacement of thrown object by compression d at time interval Δt

Δt = time intervals

d_n = the compression amount of the spring in cm

Δt(ms)	$\Delta \boldsymbol{x}_1(d_1 = 1$ cm)	$\Delta \boldsymbol{x}_2(d_2 = 2$ cm)	$\Delta \boldsymbol{x}_3(d_3 = 3$ cm)	$\Delta \boldsymbol{x}_4(d_4 = 4$ cm)
0 - 50	1	2.1	3.2	4.3
0 - 100	2.1	4.3	6.5	8.6
0 - 150	3.2	6.5	9.8	12.8
0 - 200	4.3	8.7	13.1	16.1
0 - 250	5.4	10.9	16.4	20.4
0 - 300	6.5	13.1	19.6	24.7
0 - 350	7.6	15.3	22.9	29
0 - 400	8.7	17.5	26.1	33.4

Plot 1.1



Using Python to find average velocities:

$v_{av,1}$=0.0219 cm/ms

$v_{av,2}$=0.0439 cm/ms

$v_{av,3}$=0.0654 cm/ms

$v_{av,4}$=0.0875 cm/ms

Table 1.2

U_{el} = elastic potential energy of spring by compression d (Unitless since using formula 2)

K(d) = kinetic energy of the object after release from the spring by compression d. (g * cm^2 / ms^2)

Δd(cm)	v_{av} (cm / ms)	K(d) (g * cm^2 / ms^2)	U_{el}
1	0.0219	0.1	E
2	0.0439	0. 405	4E
3	0.0654	0. 898	9E
4	0.0875	1.61	16E

m_{puck} = 420 gr

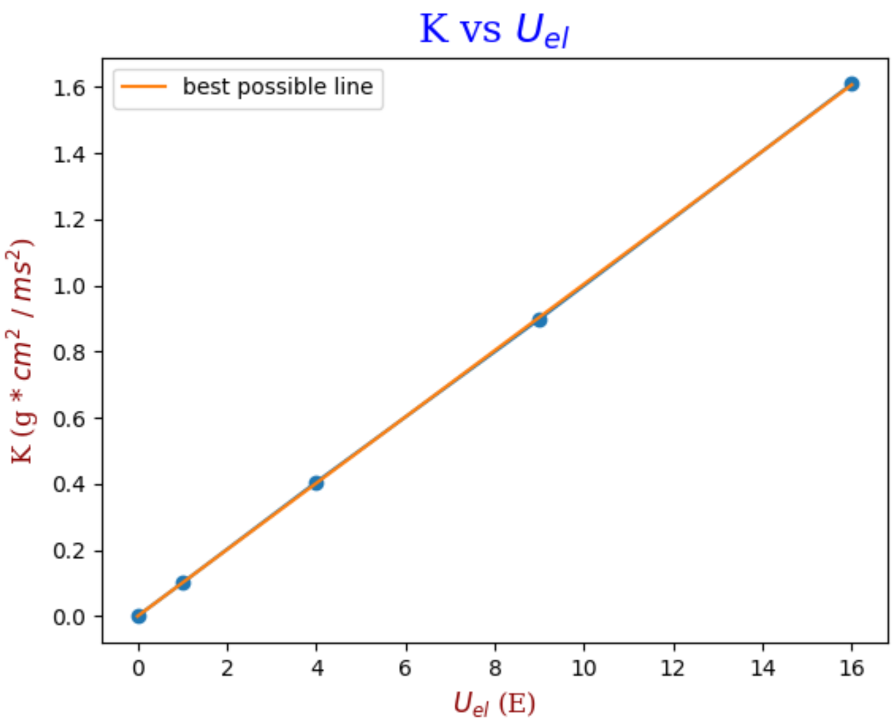
$K(1) = 1/2*420*0.0219^2 = 0.1$ g * cm^2 / ms^2

$K(2) = 2/2*420*0.0439^2 = 0.405$ g * cm^2 / ms^2

$K(3) = 1/2*420*0.0654^2 = 0.898$ g * cm^2 / ms^2

$K(4) = 1/2*420*0.0875^2 = 1.61$ g * cm^2 / ms^2

Plot 1.2



Using Python, the slope of the best possible line m = 0.1.

Error Percentage:

Since the elastic potential energy is not calculated explicitly, the error rate can be found by using the slope as 1E, calculating the percentage difference between assuming values and each experimental value, and taking the average of the error rates. (1E = 0.1)

d = 1 => K(1) ≈ 1E => |K(1) - 1E| / 0.1 * 100 => |0.1 - 0.1| / 0.1 * 100 = 0 %

d = 2 => K(2) ≈ 4E => |K(2) - 4E| / 0.4 * 100 => |0.405 - 0.4| / 0.4 * 100 = 1.25%

d = 3 => K(3) ≈ 9E => |K(3) - 9E| / 0.9 * 100 => |0.898 - 0.9| / 0.9 * 100 =

0.222%

d = 4 => K(4) ≈ 16E => |K(4) - 16E| / 1.6 * 100 => |1.61 - 1.6| / 1.6 * 100 =

0.625 %

Error Percentage = (0 + 1.25 + 0.222 + 0.625) / 4 = 0.524 %

Conclusion:

In conclusion, the best possible line in *plot 1.2* shows that kinetic energy and elastic potential energy increase proportionally (formula 2). Therefore, elastic potential energy was fully converted to kinetic energy in that experiment (formula 4). The error percentage is negligible for some reasons:

1. The angle between the spring and the air table was constant in the experiment.
2. The puck was thrown from the middle of the spring all the time.
3. The surface was frictionless.
4. No force was given from the student to the puck while throwing the puck.

Part B Conversion of Kinetic Energy to Gravitational Potential Energy:

Objective:

The purpose of this part of the experiment is to indicate whether the object's kinetic energy can be fully converted to gravitational potential energy. In part A, the conversion between kinetic and elastic potential energy was examined. Therefore, in that part, it will be assumed that the elastic potential energy can be fully converted to kinetic energy. The same technique from part A to find elastic potential energy will be used. In other words, gravitational potential energies will be determined with different but proportional starting elastic potential energies. As a result, whether the gravitational potential energy also increases with the same proportion will be examined. Finally, the error will be found by comparing the experimental and theoretical results. As a result, observing that the energy is conserved while transforming from kinetic energy to gravitational potential energy will be accomplished.

Theory:

1) $U_{\mathrm{el}} = 1/2*k*x^2$ [2]

2) $U_{\mathrm{el}} \sim x^2$

3) $K = 1/2*m*v^2$ [2]

4) $U_{\mathrm{grav}} = m*g*h$ [2]

5) $1/2*k*x^2 = m*g*h$ [2]

6) $h \sim x^2$ (when m, g, k is constant)

7) $1/2*k*x^2 = 1/2*m*v^2$ [2]

8) $m*g*h = 1/2*m*v^2$

9) $g = 9.8*m*s^{-2} = 9.8*\mathrm{cm}*\mathrm{ms}^{-2}*10^{-6}$ [3]

(k, x = force constant and the compression amount of the spring respectively; g = acceleration due to gravity; v, m, h = velocity, mass, and height of the object, respectively)

Formula 1, 2, 3, and 7 were explained in part A.

Gravitational potential energy depends on the mass, gravitational acceleration, and height of the object (formula 4). Suppose an object's mass is known and assumes that the gravitational acceleration is constant (formula 9). In that case, height is the only unknown to calculate gravitational potential energy. The height can be found by measuring the height of the last position of an object that can reach after it is launched on a friction-reduced surface.

Assuming that formula 5 is correct and formulas 5 and 7 are equalized; theoretically, the kinetic and potential energies must be the same for the same elastic potential energy (formula 8). After using the proportional compression amounts of the spring and finding the gravitational potential energies, if the ratio is directly proportional with the 6th formula, the kinetic energy is conserved while the elastic potential energy is transformed into gravitational potential energy (formulas 5, 7, and 8).

Setup of Experiment:

Equipment List:

1) Air Table
2) Puck
3) Spark Timer
4) Spring
5) Carbon Paper
6) 30 Cm Ruler
7) Scientific Calculator
8) Balance
9) Wooden cube

Procedure and Data:

1) First, measure the weight of the puck.
2) Then fix the spring at the bottom of the air table.
3) Then compress the spring at certain intervals and mark it on carbon paper by writing the amount of compression in centimeters.
4) Place the wooden cube beneath the middle of the air table to give some inclination to the air table. The cube has a number on it indicating the sine of the angle of inclination.
5) Use the marked points one by one to compress the spring and throw the puck on carbon paper with the power of the spring.
6) Measure the maximum point the puck can reach using traces marked on carbon paper and save the values in the row that intersects the corresponding compression amount column in table 2.1.
7) Using measured maximum points recorded in table 2.1, find each height using sine of the angle and record them in table 2.1.
8) Using formulas 2 and 4, find the potential energies (using found height and $g = 9.8 * \mathrm{cm} * \mathrm{ms}^{-2} * 10^{-6}$) and elastic potential energies (using compression lengths) for all compression amounts. Record these data to corresponding columns of table 2.1. (If the elastic potential energy due to compression by 1 cm is called 1E, the energy gaining by 2 cm compression can be called 4E and so on.)
9) Plot U_{el} vs. U_{grav} graph using table 2.1 and draw the best possible line.
10) Determine the best possible plot line 2.1 indicates formula 5. (Linear equation) and calculate the error percentage.

Table 2.1

$\Delta \boldsymbol{x}_d$ = the maximum point of the thrown puck can reach by compression d

h_d = the maximum height of thrown puck can reach by compression d

d_n = the compression amount of the spring in cm

U_{el} = elastic potential energy of spring by compression d (Unitless since using formula 2)

$U_{\mathrm{grav}}(\mathrm{d})$ = gravitational potential energy of the object at the maximum height for compression d cm. (g * cm^2 / ms^2)

Δd(cm)	$\Delta \boldsymbol{x}_d$ (cm)	h_d(cm)	U_{el}	$U_{\mathrm{grav}}(\mathrm{d})$(g * cm^2 / ms^2)
1	2.6	0.26	E	0.00108
2	9.1	0.91	4E	0.00375
3	24.5	2.45	9E	0.0101
4	41.5	4.15	16E	0.0171

m_{puck} = 420 gr

The sine value of the cube = 0.1

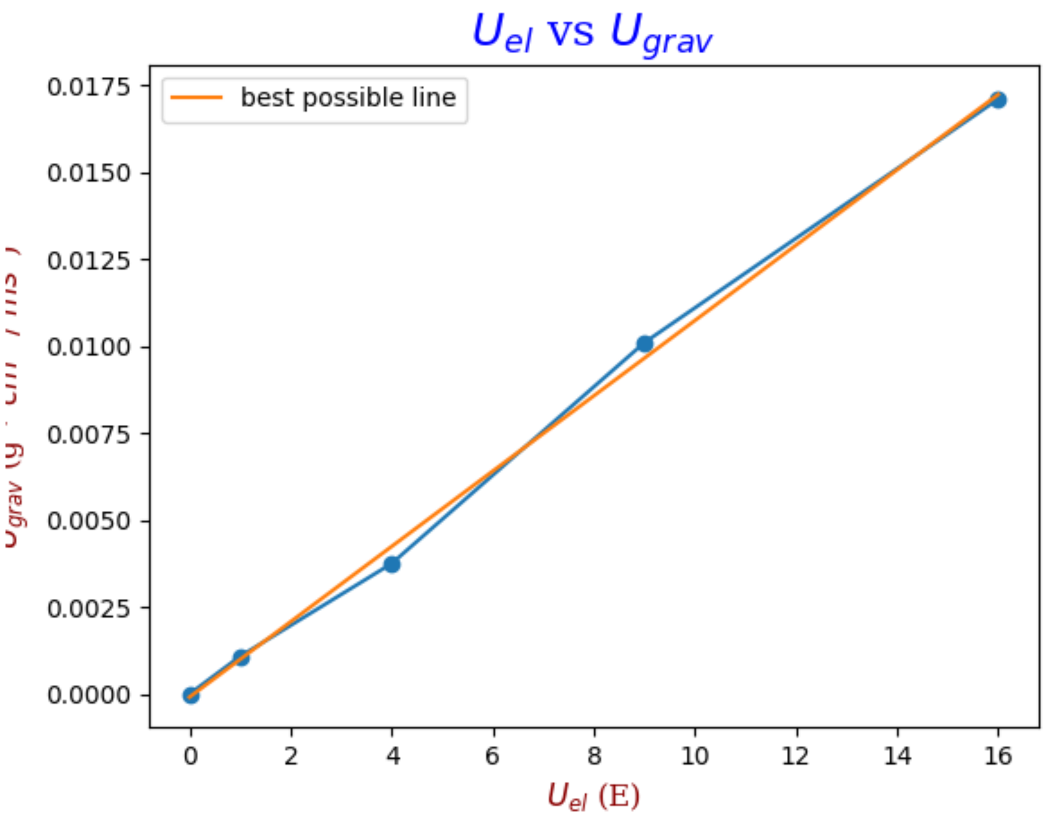
$U_{\mathrm{grav}}(1) = 420*9.8*10^{-6}*0.26 = 0.00108$ g * cm^2 / ms^2

$U_{\mathrm{grav}}(2) = 420*9.8*10^{-6}*0.91 = 0.00375$ g * cm^2 / ms^2

$U_{\mathrm{grav}}(3) = 420*9.8*10^{-6}*2.45 = 0.0101$ g * cm^2 / ms^2

$U_{\mathrm{grav}}(4) = 420*9.8*10^{-6}*4.15 = 0.0171$ g * cm^2 / ms^2

Plot 2.1



Using Python, the slope of the best possible line m = 0.00108.

Error Percentage:

Since the elastic potential energy is not calculated explicitly, the error rate can be found by using the slope as 1E, calculating the percentage difference between assuming values and each experimental value, and taking the average of the error rates. (1E = 0.00108)

d = 1 => $U_{grav}(1) \approx 1E$ => $|U_{grav}(1) - 1E|$ / 0.00108 * 100 => |0.00108 - 0.00108| / 0.00108 * 100 = 0 %

d = 2 => $U_{grav}(2) \approx 4E$ => $|U_{grav}(2) - 4E|$ / 0.00432 * 100 => |0.00375 - 0.00432| / 0.00432 * 100 = 13.19 %

d = 3 => $U_{grav}(3) \approx 9E$ => $|U_{grav}(3) - 9E|$ / 0.00972 * 100 => |0.0101 - 0.00972| / 0.00972 * 100 = 3.91 %

d = 4 => $U_{\mathrm{grav}}(4) \approx 16E$ => $|U_{\mathrm{grav}}(4) - 16E|$ / 0.01728 * 100 => |0.0171 - 0.01728| / 0.01728 * 100 = 1.04 %

Error Percentage = (0 + 13.19 + 3.91 + 1.04) / 4 = 4.535 %

Conclusion:

In conclusion, the best possible line in *plot 2.1* shows that gravitational and elastic potential energy increase proportionally (formula 5). Being proved formula 7, formula 8 is held. Therefore, kinetic energy was fully converted to gravitational potential energy in that experiment (formula 8). The error percentage is 4.535 %, and it is in an acceptable range. However, some of the possible reasons for this relatively high error percentage:

1. If the puck wasn't thrown from the middle of the spring, the puck had some horizontal velocity; thus, the gravitational potential energy was decreased.
2. If the student gave some force to the puck unintentionally while throwing the puck, the gravitational potential energy was increased.
3. If the spring is not pulled precisely to the specified values, the potential energy may be affected.

Part C Conservation of Kinetic Energy in Elastic Collision:

Objective:

This part of the experiment aims to indicate whether the total kinetic energy of collided objects is conserved after elastic collision. Initial kinetic energies will be used from part A. The kinetic energies of objects after the collision will be determined with different starting kinetic energies. Finally, the error will be found by comparing the experimental result and theoretical result. As a result, observing that the total kinetic energy is conserved after the collision will be accomplished.

Theory:

1) $K = 1/2 * m * v^2$ [2]

2) $1/2 * m * v_{\mathrm{A1}}^2 + 1/2 * m * v_{\mathrm{B1}}^2 = 1/2 * m * v_{\mathrm{A2}}^2 + 1/2 * m * v_{\mathrm{B2}}^2$ [1]

(V_d, m = speed, the mass of the object, respectively)

Kinetic Energy was discussed in part A. If the masses of the objects are known, finding their velocities after the collision is sufficient to find their total kinetic energy. The velocities after the collision can be calculated by periodically measuring the positions of objects after they have collided on a friction-reduced surface. Suppose the final and initial total kinetic energies are equal (formula 2). In that case, the kinetic energy is conserved while the elastic collision of two identical objects.

Setup of Experiment:

Equipment List:

1) Air Table
2) Two Identical Puck
3) Spark Timer

4) Two Identical Spring
5) Carbon Paper
6) 30 Cm Ruler
7) Scientific Calculator
8) Balance

Procedure and Data:

1) First, measure the weight of one of the pucks.
2) Then fix two springs on opposite sides of the air table and make sure that they makes 45 degree angle with air table.
3) Then compress the springs at certain intervals and mark them on carbon paper by writing the amount of compression in centimeters.
4) Use the marked points one by one to compress the springs and throw the pucks with the power of the springs on carbon paper.
5) Measure the displacements of two objects after the elastic collision using traces marked at certain time intervals on carbon paper. Then, save the values in the row that intersects the corresponding compression amount columns in tables 3.1 and 3.2 (2 tables for 2 objects).
6) Plot x vs. t graphs at plots 3.1 and 3.2 using table 3.1 and 3.2. From that, find all average velocities. Record them in table 3.3.
7) Using formula 1 and found speeds, find the kinetic energies of the objects after the collision for all compression amounts. Record these data as well as initial total kinetic energies to corresponding columns of table 3.3.
8) Divide final kinetic energies by initial kinetic energies and record them at the corresponding column of table 3.3 (formula 2).
9) Find the error percentage of elastic collision by taking the average of the final and initial kinetic energies divisions.

Table 3.1

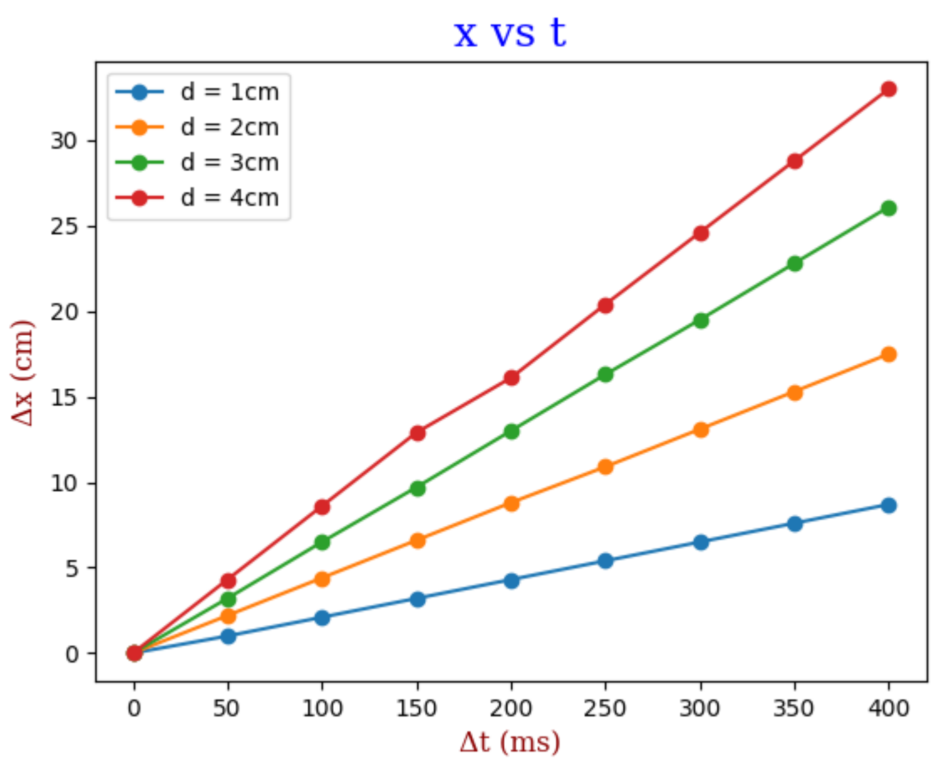
$\Delta\, \boldsymbol{x}_d$ = displacement of thrown object 1 by compression d at time interval $\Delta \boldsymbol{t}$, starting from collision.

$\Delta \boldsymbol{t}$ = time intervals

d_n = the compression amount of the spring in cm

$\Delta \boldsymbol{t}$(ms)	$\Delta\, \boldsymbol{x}_1(d_1$ = 1 cm)	$\Delta\, \boldsymbol{x}_2(d_2$ = 2 cm)	$\Delta\, \boldsymbol{x}_3(d_3$ = 3 cm)	$\Delta\, \boldsymbol{x}_4(d_4$ = 4 cm)
0-50	1	2.2	3.2	4.3
0-100	2.1	4.4	6.5	8.6
0-150	3.2	6.6	9.7	12.9
0-200	4.3	8.8	13	16.1
0-250	5.4	10.9	16.3	20.4
0-300	6.5	13.1	19.5	24.6
0-350	7.6	15.3	22.8	28.8
0-400	8.7	17.5	26.1	33

Plot 3.1



Using Python to find average velocities:

$v_{av,1}$=0.0219 cm/ms

$v_{av,2}$=0.0437 cm/ms

$v_{av,3}$=0.0652 cm/ms

$v_{av,4}$=0.0817 cm/ms

Table 3.2

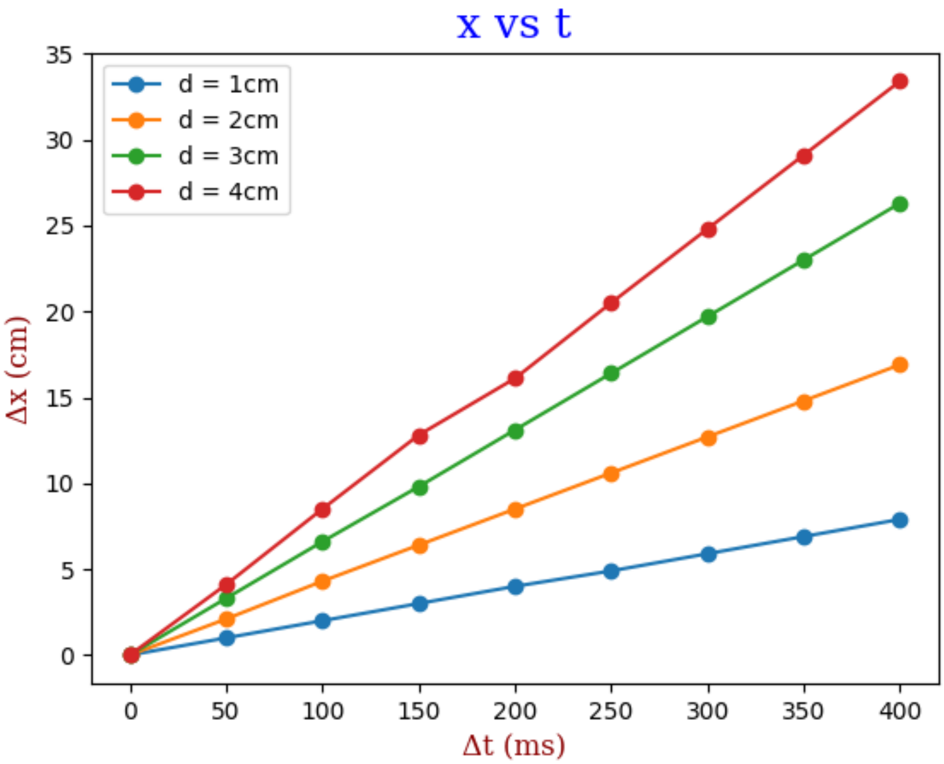
$\Delta\, \boldsymbol{x}_d$ = displacement of thrown object 2 by compression d at time interval $\Delta \boldsymbol{t}$, starting from collision.

$\Delta \boldsymbol{t}$ = time intervals

d_n = the compression amount of the spring in cm

$\Delta \boldsymbol{t}$(ms)	$\Delta\, \boldsymbol{x}_1(d_1$ = 1 cm)	$\Delta\, \boldsymbol{x}_2(d_2$ = 2 cm)	$\Delta\, \boldsymbol{x}_3(d_3$ = 3 cm)	$\Delta\, \boldsymbol{x}_4(d_4$ = 4 cm)
0-50	1	2.1	3.3	4.1
0-100	2	4.3	6.6	8.5
0-150	3	6.4	9.8	12.8
0-200	4	8.5	13.1	16.1
0-250	4.9	10.6	16.4	20.5
0-300	5.9	12.7	19.7	24.8
0-350	6.9	14.8	23	29.1
0-400	7.9	16.9	26.3	33.4

Plot 3.2



Using Python to find average velocities:

$v_{av,1}$=0.0197 cm/ms

$v_{av,2}$=0.0422 cm/ms

$v_{av,3}$=0.0656 cm/ms

$v_{av,4}$=0.0830 cm/ms

Table 3.3

$K_{initial}$ = total kinetic energy of the objects after release from the spring.

K_{final} = total kinetic energy of the objects after collision.

$K_{1,2}$(d) = kinetic energy of the first object after collision which threw by compression d cm. (g * cm^2 / ms^2)

$K_{2,2}$(d) = kinetic energy of the first object after collision which threw by compression d cm. (g * cm^2 / ms^2)

Δd(cm)	$v_{av,1}$ (cm/ms)	$v_{av,2}$ (cm/ms)	$K_{1,2}$(d) (g * cm^2 / ms^2)	$K_{2,2}$(d) (g * cm^2 / ms^2)	$K_{initial}$ (d) (g * cm^2 / ms^2)	K_{final} (d) (g * cm^2 / ms^2)	K_{final}/ $K_{initial}$
1	0.0219	0.0197	0.1	0. 082	0.2	0. 182	0.91
2	0.0437	0.0422	0. 401	0. 374	0. 810	0. 775	0.96
3	0.0653	0.0657	0. 893	0. 904	1.8	1.797	0.99
4	0.0817	0.0830	1.40	1.45	3.22	2.85	0.89

m_{puck} = 420 gr

$K_{1,2}(1) = 1/2*420*0.0219^2 = 0.1$ g * cm^2 / ms^2

$K_{1,2}(2) = 1/2*420*0.0437^2 = 0.401$ g * cm^2 / ms^2

$K_{1,2}(3) = 1/2*420*0.0652^2 = 0.893$ g * cm^2 / ms^2

$K_{1,2}(4) = 1/2*420*0.0817^2 = 1.40$ g * cm^2 / ms^2

$K_{2,2}(1) = 1/2*420*0.0197^2 = 0.082$ g * cm^2 / ms^2

$K_{2,2}(2) = 1/2*420*0.0422^2 = 0.374$ g * cm^2 / ms^2

$K_{2,2}(3) = 1/2*420*0.0657^2 = 0.904$ g * cm^2 / ms^2

$K_{2,2}(4) = 1/2*420*0.0830^2 = 1.45 \text{ g} * \text{cm}^2 / \text{ms}^2$

Error Percentage:

(0.09 + 0.04 + 0.01 + 0.11) / 4 * 100 = 6.25%

Conclusion:

In conclusion, the ratios between final and initial kinetic energies show that kinetic energy is conserved in elastic collisions. The error percentage is 6.25%, which is acceptable. Nevertheless, some of the possible reasons for this relatively high error percentage:

1. The pucks may lose energy when they collide since, in real life, none of the collisions is elastic.
2. If the student unintentionally gave some force to the pucks while throwing the pucks, the kinetic energy may increase.
3. Pulled two of them simultaneously, the spring may not be pulled precisely to the specified values. Then the kinetic energy may be affected.
4. The energy lost may vary depending on the severity and size of the collision.

All of the experiments show that energy is conserved in conversions between the elastic potential to kinetic energies, kinetic to gravitational potential energies, and kinetic to kinetic energies.

References:

[1]"Elastic Collisions in One Dimension | Physics”, Courses.lumenlearning.com, 2021. [Online]. Available: https://courses.lumenlearning.com/physics/chapter/8-4-elastic-collisions-in-one-dimension/. [Accessed: 31- Oct- 2021]

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YOUTUBE LINK: https://youtu.be/MwqUKz1Q2LY