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**Lab 6: Conservation of Momentum**

6/25/2018

PHYS 261 – 005

With:

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**Objective**

The objective for this lab is to be able to measure the conserved momentum within a system involving many different elastic and inelastic collision scenarios.

**Theory**

The theory being tested is that the total momentum within a system is conserved in the absence of external forces, which is Newton’s First Law. Newton’s Third Law then states that forces inside the system have counterforces that are equivalent in magnitude but opposite in polarity. Momentum is a conserved quantity defined found by p=mv. Applying the laws discussed above, the conservation of momentum after the collision of objects in the system can be expresses as

Eq. 7-1

in a two-body system with a total mass *M* equivalent to *m1+m2* and individual velocities *v1* and *v2*. Because the total momentum in a system cannot change, and the mass does not change in these two-body collisions, the velocity of the center of mass of the system, *vcm*, will also not change, even after the events of collision where new individual velocities, *v’1* and *v’2*, are in place. Thus, we can rewrite Eq. 7-1 to the new velocities:

Eq. 7-2

Combining Eq. 7-1 and Eq. 7-2 produces:

Eq. 7-3

This is the primary equation for analysis of the collisions, whether elastic or inelastic.

Additionally, in the case of elastic collisions, the kinetic energy must also be conserved:

Eq. 7-4

In these experiments, the momentum cannot be entirely conserved due to the interference of frictional forces. Measures are taken to minimize the effect of frictional forces in this experiment, such as a low-friction track and magnetic repulsion for the elastic collisions.

**Procedure**

The procedures in the lab involve using two of the ultrasonic motion detectors to measure the velocities of two carts on the low-friction track. One of the carts was designated as cart 1, and the other as cart 2, which was constant for all procedures, e.g. cart 1 was the same cart in all procedures. Also, all procedures would see cart 1 moved towards cart 2, where cart 2’s initial velocity would always be zero. In other words, the only movement experienced by cart 2 would always be from the collision. Each procedure saw a different configuration of the carts and was trialed three times for consistency. For the sake of brevity, the configurations for each procedure are shown below.

|  |  |  |  |
| --- | --- | --- | --- |
| Procedure | Collision Type | Cart 1 Additional Mass | Cart 2 Additional Mass |
| A | Elastic | 0 grams | 0 grams |
| B | Elastic | 500 grams | 0 grams |
| C | Elastic | 0 grams | 500 grams |
| D | Inelastic | 0 grams | 0 grams |
| E | Inelastic | 500 grams | 0 grams |
| F | Inelastic | 0 grams | 500 grams |

**Table 7-1.** The setup configurations for each procedure in the experiment. Each configuration was trialed three times.

**Data**

Shown below is the table of all the readings for the procedures defined in Table 7-1.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Procedure | Trial # | v1 (m/s) | v2 (m/s) | v'1 (m/s) | v'2 (m/s) |
| A | 1 | 0.271 | 0 | 0.016 | 0.217 |
| 2 | 0.15 | 0 | 0.117 | 0.000 |
| 3 | 0.2513 | 0 | 0.000 | 0.202 |
|  |  |  |  |  |  |
| B | 1 | 0.1601 | 0 | 0.028 | 0.190 |
| 2 | 0.1632 | 0 | 0.029 | 0.183 |
| 3 | 0.1999 | 0 | 0.049 | 0.252 |
|  |  |  |  |  |  |
| C | 1 | 0.2421 | 0 | 0.062 | 0.137 |
| 2 | 0.3028 | 0 | 0.043 | 0.160 |
| 3 | 0.2044 | 0 | 0.060 | 0.121 |
|  |  |  |  |  |  |
| D | 1 | 0.3459 | 0 | 0.141 | 0.136 |
| 2 | 0.3144 | 0 | 0.127 | 0.135 |
| 3 | 0.2402 | 0 | 0.104 | 0.104 |
|  |  |  |  |  |  |
| E | 1 | 0.2054 | 0 | 0.108 | 0.107 |
| 2 | 0.2704 | 0 | 0.164 | 0.165 |
| 3 | 0.2484 | 0 | 0.157 | 0.152 |
|  |  |  |  |  |  |
| F | 1 | 0.3738 | 0 | 0.108 | 0.109 |
| 2 | 0.3043 | 0 | 0.094 | 0.095 |
| 3 | 0.3886 | 0 | 0.120 | 0.120 |

**Table 7-2.** The table of the velocity readings for each trial from all the procedures.

**Analysis**

Using the information compiled in Table 7-2 and the equation for momentum, we can derive the net momentum for each trial run in the experiment. Seeing the momentum of the system before and after collision will allow us to see how the momentum was conserved.

The momentum calculations for each procedure are given below.

|  |  |  |  |
| --- | --- | --- | --- |
|  | m1 (kg) | 0.5072 |  |
|  | m2 (kg) | 0.5102 |  |
| Procedure | pnet (N·s) | p'net (N·s) | %lossp |
| A | 0.137 | 0.119 | 13.660 |
| 0.076 | 0.060 | 21.733 |
| 0.127 | 0.103 | 19.143 |
|  |  |  |  |
| B | 0.081 | 0.111 | 36.492 |
| 0.083 | 0.108 | 30.750 |
| 0.101 | 0.153 | 51.336 |
|  |  |  |  |
| C | 0.123 | 0.101 | 17.551 |
| 0.154 | 0.103 | 32.813 |
| 0.104 | 0.092 | 10.804 |
|  |  |  |  |
| D | 0.175 | 0.141 | 19.628 |
| 0.159 | 0.133 | 16.476 |
| 0.122 | 0.106 | 13.107 |
|  |  |  |  |
| E | 0.104 | 0.109 | 5.079 |
| 0.137 | 0.167 | 22.032 |
| 0.126 | 0.157 | 24.799 |
|  |  |  |  |
| F | 0.190 | 0.110 | 41.829 |
| 0.154 | 0.096 | 37.871 |
| 0.197 | 0.122 | 38.212 |

**Table 7-3.** The table containing the derived net momenta before and after collision and the percentage of the momentum lost in the process.

In a similar fashion, we can calculate the total energies in the system before and after the collision. Because the system takes place on a level track with no vertical variation, we can ignore potential energy and focus solely on the kinetic energy exchange. The energy calculations are given on the next page.

|  |  |  |  |
| --- | --- | --- | --- |
|  | m1 (kg) | 0.5072 |  |
|  | m2 (kg) | 0.5102 |  |
| Procedure | E (J) | E' (J) | %lossE |
| A | 0.019 | 0.012 | 35.442 |
| 0.006 | 0.003 | 38.743 |
| 0.016 | 0.010 | 35.005 |
|  |  |  |  |
| B | 0.007 | 0.009 | 44.474 |
| 0.007 | 0.009 | 30.170 |
| 0.010 | 0.017 | 65.875 |
|  |  |  |  |
| C | 0.015 | 0.006 | 61.324 |
| 0.023 | 0.007 | 70.073 |
| 0.011 | 0.005 | 55.871 |
|  |  |  |  |
| D | 0.030 | 0.010 | 67.788 |
| 0.025 | 0.009 | 65.184 |
| 0.015 | 0.006 | 62.359 |
|  |  |  |  |
| E | 0.011 | 0.006 | 44.952 |
| 0.019 | 0.014 | 25.761 |
| 0.016 | 0.012 | 22.340 |
|  |  |  |  |
| F | 0.035 | 0.006 | 83.130 |
| 0.023 | 0.005 | 80.757 |
| 0.038 | 0.007 | 80.967 |

**Table 7-4.** The table of the net energies before and after collision of the carts, and the percentages of energy lost in the process of each trial.

**Extension of theory:**

Given Eq. 7-3, we can derive a formula to calculate the expected final velocities of the colliding bodies in an elastic collision.

We can eliminate the initial cart 2 momentum because it begins still.

Kinetic energies would be conserved because this is an elastic collision.

According to the second step:

We sub this back into step 4.

Which we expand and multiply by *m2*.

Then we factor out *v’1*.

This is a quadratic equation with an independent variable *v’1*, which we can solve for using the quadratic formula. Doing so results in the following:

Which simplifies to

However, it cannot be the positive solution because that would mean

Which is not true because there was a collision and cart 1 is not an unstoppable force, so to speak. Therefore, the only other solution is the other root:

Eq. 7-5a

If we take this known velocity and plug it into step 7, we can find *v’2*.

Eq. 7-5b

Using these two equations we can get what the expected velocities for the elastic trials were.

|  |  |  |  |
| --- | --- | --- | --- |
| Procedure | Trial # | v'1 (m/s) Expected | v'2 (m/s) Expected |
| A | 1 | -0.000799096 | 0.270200904 |
| 2 | -0.000442304 | 0.149557696 |
| 3 | -0.000741006 | 0.250558994 |
|  |  |  |  |
| B | 1 | 0.052438184 | 0.212538184 |
| 2 | 0.053453539 | 0.216653539 |
| 3 | 0.065474035 | 0.265374035 |
|  |  |  |  |
| C | 1 | -0.080253262 | 0.161846738 |
| 2 | -0.100374588 | 0.202425412 |
| 3 | -0.067756162 | 0.136643838 |

**Table 7-5.** The expected final velocities for each of the elastic trials.

These values do not match up very well with the experimental values. The transfer of kinetic energy followed the proportions, and the momentum seems to be conserved, but the raw velocities between this table and Table 7-2 simply do not match. One of the main discrepancies is the presence of negative velocities in this table. It is consistent, however. When the masses are the same it seems that most of the energy just gets handed to cart 2, but whenever one cart is more massive than the other, the larger one does not like to move as much, which is what Procedures B and C show here.

Everything just done for elastic collisions can also be done for the inelastic collision procedures.

We can start with Eq. 7-3.

But because the collision is inelastic, but cart one and cart 2 will have same final velocity *v’*. We can also take cart 2’s initial momentum out because again, it is motionless at the beginning.

Which gives us the result

Eq. 7-6

Applying this equation our results for the expected final velocities are as follows on the next page:

|  |  |  |
| --- | --- | --- |
| Procedure | Trial # | v' (m/s) expected |
| D | 1 | 0.172440024 |
| 2 | 0.156736466 |
| 3 | 0.119745862 |
|  |  |  |
| E | 1 | 0.136337736 |
| 2 | 0.179482589 |
| 3 | 0.164879715 |
|  |  |  |
| F | 1 | 0.124944879 |
| 2 | 0.10171409 |
| 3 | 0.129891868 |

**Table 7-6.** The expected final velocities for all the trials in the inelastic collision series of procedures.

This data is a little bit more consistent with the information from Table 7-2. Table 7-2’s final values show pretty close and, in some cases, perfect splits between the velocities of carts 1 and 2, and most of that data matches closely to the values shown here.

**Conclusions**

Based on all these results, it is hard for me to say with a clear conscience that the information presented supports the law of conservation of momentum. While the data given in the inelastic collisions portion matches up relatively well with the expected values, the actual values for the elastic collisions were way off from those of the expected calculations. Within the experiment, even though these trials were run on a frictionless track, we saw up to 50% loss of the net momentum within the system. There is no way we can say that this upholds the law. I disagree that the information presented here is a good case for the law of conservation of mass, and that it supports the theory presented, but the objective of the lab has still been achieved.