Verification of the Linear Momentum Conservation Law Using Linear Air Track

Putu Chrisnaria Hasian Sinaga

Abstrak. The progress of physics is based on facts and experimental data. Therefore, it is very important to prove or verify some theories experimentally. One of fundamental laws of physics is momentum conservation law. It has been used extensively in many mechanical problems involving collisions. However, the use of this law is usually taken for granted and rarely been demonstrated experimentally due to technical difficulties in determining the instantaneous velocities of the objects before and after the collision takes place. These difficulties can be solved by using Linear Air Track to prove the conservation law of momentum by colliding two vehicles on the track, because Linear Air Track can provide linear and stable motion with negligible friction force between vehicles and its track. By using photographic technique, the image can be quantified and analyzed to obtain the instantaneous velocities the object before and after collision. As a temporary hypothesis Linear Air Track can be use to verify the linear momentum conservation law on any collision between two objects. Due to considerably high degree of measurement uncertainties involved in the experiment, the hypothesis will be accepted if the comparative ration between the final and initial total momentum of the system is up or equal to 90%. The result from this experiment shows that the percentages of accuracy are up to 90%. Then, we may conclude that Linear Air Track can be used to verify the linear momentum conservation law on any collision between two objects.

Key words: Linear Air Track, Conservation Law of Momentum, Collision

Introduction

Linear Air Track is a tool that can provide linear and stable motion with negligible friction force between vehicles and its track (Griffin and George Ltd). Unfortunately, there are only few experiments that have been using the Linear Air Track in the Physics Laboratory of Widya Mandala Surabaya Catholic University (WMSCU). Therefore, it opens opportunities for exploring the Linear Air Track to solve delicate mechanical problems that need certain types of uniform linear motion to simplify the problem.

The progress of physics is based on facts and experimental data. Therefore, it is very important to prove or verify some theories experimentally. One of fundamental laws of physics is momentum conservation law. It has been used extensively in many mechanical problems involving collisions. However, the use of this law is usually taken for granted and rarely been demonstrated experimentally due to technical difficulties in determining the instantaneous velocities of the objects before and after the collision takes place.

According to the research done by Tanti Yunitasari, it has been found out that photographic technique can be used to identify specific types of linear motion such as uniformly linear motion and uniformly accelerated linear motion provided by Linear Air Track (Yunitasari, 2006). This brings a new hope that the same technique would be able to be used to verify the momentum conservation law applied to collisions between two objects on the Linear Air Track. However, due to considerably high degree of measurement uncertainties involved in the experiment, it is a big challenge to verify the momentum conservation law in the Physics Laboratory of WMSCU using the Linear Air Track.

From the described problems above and the previous research that Linear Air Track can be used to identify uniformly linear motion and uniformly accelerated linear motion, the writer would like to propose *verification of the linear momentum conservation law using Linear Air Track* as the main topic of her research thesis.

Statement of the Problem

The research question that the writer would like to raise is whether or not the linear momentum conservation law will apply to collisions between two objects on Linear Air Track.

Hypothesis

Linear Air Track can be used to verify the linear momentum conservation law on any collision between two objects.

Literature Reviews

1. Momentum and Impulse

The linear momentum of a body is defined as the product of its mass and velocity. All objects have mass; so if an object is moving, then it has momentum - it has its mass in motion. The amount of momentum which an object has depends upon two variables: how much stuff is moving and how fast the stuff is moving. Momentum depends upon the variables mass and velocity. In physics, the symbol of momentum is the lower case **p**.

If we let m represent the mass of a body and **v** represent its velocity, then its momentum **p** can be rewritten as

$$\mathbf{p} = m\mathbf{v} \quad (1)$$

where,
m : the object's mass (kg)
$\mathbf{v}$: the object's velocity (m/s)
$\mathbf{p}$: the object's momentum (kg m/s)

Since velocity is a vector and mass is a scalar then momentum is a vector. (Giancoli, 1995).

To help the reader identify the type of physical quantity being discussed, any vector quantity will be written in bold face, while the scalar quantity will be written in italic.

The direction of the momentum is the same as the direction of the velocity, and the magnitude of the momentum is p = mv. The equation illustrates that momentum is directly proportional to an object's mass and directly proportional to the object's velocity. The unit of momentum would be mass unit times velocity unit. The standard metric unit of momentum is the kg.m/s. (Henderson, 1996).

From the definition of momentum, it becomes obvious that an object has a large momentum if either its mass or its velocity is large. Both variables are of equal importance in determining the momentum of an object. Consider a Mack truck and a roller skate moving down the street at the same speed. The considerably greater mass of the Mack truck gives it a considerably greater momentum. Yet if the Mack truck were at rest, then the momentum of the least massive roller skate would be the greatest. The momentum of any object which is at rest is 0. Objects at rest do not have momentum - they do not have any "mass in motion." Both variables - mass and velocity - are important in comparing the momentum of two objects. For the objects which have the same mass, the one which has the higher velocity will have greater momentum. On the other hand, an object having a huge mass, even though it moves slowly, it will have a very great momentum.

2. The relation between Impulse and Momentum

Suppose that a net force acts to an object of constant mass during time interval Δt, and then we get:

$$\mathbf{F} = m\mathbf{a}$$
$$\square\mathbf{p}\square\square t\square = \square\square m\mathbf{a}$$
$$\square\mathbf{p} = m\mathbf{a}\square t$$
$$m\,\mathbf{v}_t - m\mathbf{v}_0 = m\mathbf{a}\square t$$
$$m\,\mathbf{v}_t = m\,(\mathbf{v}_0 + \mathbf{a}\,\Delta t)$$
$$m\,\mathbf{v}_t = m\,\mathbf{v}_0 + \mathbf{F}\,\Delta t$$
$$m\,\mathbf{v}_t - m\,\mathbf{v}_0 = \mathbf{F}\,\Delta t$$

where, $m\,\mathbf{v}_0$: Initial Momentum
$m\,\mathbf{v}_t$: Final Momentum

$\mathbf{F}\,\Delta t$ is called Impulse **I** produced by the net force **F** during Δt time interval. On the other hand, ($m\,\mathbf{v}_t - m\,\mathbf{v}_0$) is called the momentum change. It means that the impulse on an object equals to the momentum change of the object.

$$\mathbf{I} = m\,\mathbf{v}_t - m\,\mathbf{v}_0 \quad (2)$$

3. Conservation Law of Momentum and Collision

Suppose that the instantaneous velocities of each object just before the collision are $\mathbf{v_1}$ and $\mathbf{v_2}$ and just after collision become $\mathbf{v_1}'$ and $\mathbf{v_2}'$. If the time interval of contact is Δt, the contact force on the first object is called $\mathbf{F_{12}}$ and the contact force on the second object is called $\mathbf{F_{21}}$, then by the third Newton's law we get :

$$\mathbf{F_{12}} = - \mathbf{F_{21}}$$

During the contact time interval Δt, the equation will be:

$$\mathbf{F_{12}}\,\Delta t = - \mathbf{F_{21}}\,\Delta t$$

$$(m_1\,\mathbf{v_1}' - m_1\,\mathbf{v_1}) = - (m_2\,\mathbf{v_2}' - m_2\,\mathbf{v_2})$$

$$m_1\,\mathbf{v_1} + m_2\,\mathbf{v_2} = m_1\,\mathbf{v_1}' + m_2\,\mathbf{v_2}' \quad (3)$$

For any collision between two objects (object 1 and 2) in an isolated system, the total momentum of the two objects before the collision is equal to the total momentum of the two objects after the collision. (Henderson, 1996).

The law of conservation of momentum is a fundamental law of nature, and it states that the total momentum of a closed system of objects (which has no interactions with external agents) is constant. One of the consequences of this is that the centre of mass of any system of objects will always continue in motion with the same velocity unless acted on by a force outside the system (Wikipedia, 2007)

For collisions on a horizontal plane there is no change in the potential energy of each object, only the change in their kinetic energies will be considered. In collisions, the final condition is not same with the initial condition. Basing on the change of the total kinetic energy of the objects involved in the collisions, we may divide collisions into three groups: elastic collisions, inelastic collisions, and completely inelastic collisions.

In most collisions, some kinetic energy (KE) is lost because the collisions are not perfectly elastic. Heat is generated, the objects may be deformed, and sounds waves are created, all of which involve conversions of the kinetic energy of the objects to other forms of energy (Griffith, 2004). An elastic collision happens if the total KE before and after collision is remains the same (Kamajaya, 2003).

If the two objects are very hard and elastic and no heat is produced in the collision, then kinetic energy is conserved as well (Giancoli, 1995). By this we mean that the sum of the kinetic energies of the two objects is the same after the collision as before. If we compare the total kinetic energy before the collision with the total after the collision, they remain the same. Such a collision, in which the total KE is conserved, is called an elastic collision. So, an **elastic collision** is one in which no KE is lost. We can write the equation for conservation of total kinetic energy as:

$$\frac{1}{2}m_1 v^2{}_1 + \frac{1}{2}m_2 v^2{}_2 = \frac{1}{2}m_1 v'^2{}_1 + \frac{1}{2}m_2 v'^2{}_2$$

$$m_1 v_1^2 + m_2 v_2^2 = m_1 v_1'^2 + m_2 v_2'^2$$

$$m_1(v_1 - v_1') = \frac{m_2(v_2'^2 - v_2^2)}{v_1 + v_1'} \quad (4)$$

Using the conservation law of momentum we obtain:

$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_1' + m_2\mathbf{v}_2'$$

$$m_1(\mathbf{v}_1 - \mathbf{v}_1') = m_2(\mathbf{v}_2' - \mathbf{v}_2) \quad (5)$$

From equation (2.4) and (2.5), we will get:

$$m_2(v_2' - v_2) = \frac{m_2(v_2'^2 - v_2^2)}{v_1 + v_1'}$$

$$-\frac{v_1' - v_2'}{v_1 - v_2} = 1 \quad (6)$$

The left hand side of equation 2.6 is defined as a new physical quantity so-called the coefficient of restitution which is symbolically written as e.

$$e = -\frac{v_1' - v_2'}{v_1 - v_2} \quad (7)$$

Using the definition above then elastic collision can also be stated as collision with $e = 1$. This new physical quantity can be used further to classify collision.

Inelastic Collisions

Collisions in which kinetic energy is not conserved are called **inelastic collisions**. Some of the initial kinetic energy in such collisions is transformed into other types of energy, such as thermal or potential energy, so the total final KE is less than the total initial KE (Giancoli, 1995).

It can be shown, after some calculation, that the coefficient of restitution of inelastic collision is less than one.

$$m_1\mathbf{v}_1' + m_2\mathbf{v}_2' = m_1\mathbf{v}_1 + m_2\mathbf{v}_2 \quad (8)$$

$$m_1\mathbf{v}_1^2 + m_2\mathbf{v}_2^2 \geq m_1\mathbf{v}_1'^2 + m_2\mathbf{v}_2'^2 \geq 0 \quad (9)$$

$$(8) \rightarrow m_1(\mathbf{v}_1 - \mathbf{v}_1') = m_2(\mathbf{v}_2' - \mathbf{v}_2) \quad (8a)$$

$$(9) \rightarrow m_1(\mathbf{v}_1^2 - \mathbf{v}_1'^2) \geq m_2(\mathbf{v}_2'^2 - \mathbf{v}_2^2) \quad (9a)$$

$$\mathbf{v}_1 + \mathbf{v}_1' \geq \mathbf{v}_2' + \mathbf{v}_2$$

$$\mathbf{v}_1' - \mathbf{v}_2' \geq \mathbf{v}_2 - \mathbf{v}_1$$

$$-(\mathbf{v}_1' - \mathbf{v}_2') \leq -(\mathbf{v}_2 - \mathbf{v}_1)$$

$$-(\mathbf{v}_1' - \mathbf{v}_2') \leq \mathbf{v}_1 - \mathbf{v}_2$$

$$-\frac{(v_1' - v_2')}{v_1 - v_2} \leq 1 \quad (10)$$

As we know from the earlier, that the left hand side of equation 2.10 is defined as e, then the coefficient of restitution for the inelastic collision can be written as:

$$0 < e < 1 \quad (11)$$

It means the coefficient of restitution for the inelastic collision is less than one and more than zero.

Completely Inelastic Collisions

If two objects after collision are stick together, the collision is said to be completely inelastic (Giancoli, 1995)**.** Because they stuck together and moved as one object after the collision, we had just one final velocity to contend with (Griffith, 2004).

Even though KE is not conserved in Completely Inelastic Collisions, the total energy is conserved, and the total momentum is also conserved.

$$(\mathbf{v_1}' = \mathbf{v_2}' = \mathbf{v})$$

$$m_1 \mathbf{v_1} + m_2 \mathbf{v_2} = m_1 \mathbf{v_1}' + m_2 \mathbf{v_2}'$$

$$m_1 \mathbf{v_1} + m_2 \mathbf{v_2} = (m_1 + m_2)\mathbf{v}' \quad (12)$$

Using the definition given in equation 2.7 we can show that the coefficient of restitution of completely inelastic collision is zero.
Hence,

$$e = 0 \text{ for completely inelastic collision} \quad (13)$$

Now consider if the mass of one body, say m_1, is far greater than that of m_2 (m_1>>m_2). In that case the sum of m_1 and m_2 is approximately equal to m_1. And m_1-m_2 is approximately equal to m_1. Put these values in the conservation law of momentum equation to calculate the value of $\mathbf{v_2}$ after collision. The expression change to v2 final is $2(\mathbf{v_1} - \mathbf{v_2})$. Its physical interpretation is in case of collision between two body one of which is very heavy, the lighter body moves with twice the velocity of the heavier body less its actual velocity but in opposite direction.

Another special case is when the collision is between two bodies of equal mass. Say body m_1 moving at velocity $\mathbf{v_1}$ strikes body m_2 that is at rest ($\mathbf{v_2}$).

Putting this case in the equation derived above we will see that after the collision, the body that was moving (m_1) will start moving with velocity $\mathbf{v_2}$ and the mass m_2 will start moving with velocity $\mathbf{v_1}$. So there will be an exchange of velocities.

Now suppose one of the masses, say m_2, was at rest. In that case after the collision the moving body, m_1, will come to rest and the body that was at rest, m_2, will start moving with the velocity that m_1 had before the collision. All of these observations are for an elastic collision.This phenomenon called Newton's cradle, one of the most well-known examples of conservation of momentum, is a real life example of this special case (Wikipedia, 2007)

4. Linear Air Track

Linear Air Track has been in use for many years as a means of providing friction-free motion. In limiting the motion of bodies to one dimension Linear Air Tracks provide a simple introduction to topics such as collision processes and the conservation of momentum (Griffin and George Ltd)

One advantage of the air track is the degree of control which can be exercised over the surface along which the vehicles pass. By the use of suitable supports this can be made level to a high degree of accuracy and quantitative dynamic experiments can be carried out under conditions of small residual errors. (Griffin and George Ltd).

The use of the Linear Air Track makes possible superior quantitative results when verifying the conservation of linear momentum in an experiment. When experiments are carried out carefully, it is possible to minimize the energy "loss" for elastic collision (Inexus, 1999).

Methodology

1. List of Tools and Materials

The tools needed in this study are (1) Linear Air Track and its accessories, (2) Blowe, (3) Strobo lamp, (4) Camera and film, (5) Ruler, (6) Dark background screen, (7) Aluminum paper, (8) Waterpass, and (9) O'hauss Scale

2. Data Collection Procedure

Data were collected using the following photographic technique

1. Set up the tools according to the picture below

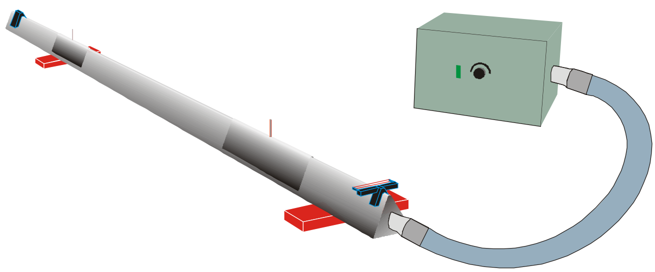

Diagram of the Linear Air Track using photographic technique, which one vehicle was at rest.

2. Arrange the track to be horizontal by using *waterpass* as a reference
3. Arrange the position and the focus of the camera to get the best image quality

4. Stick an aluminum paper on the track to be used as reference (length scale)
5. Turn on the blower and the *strobo* lamp.
6. Put a vehicle on the track at certain position and arrange the system in such a way that the vehicle is at rest.
7. Put another vehicle and press it against a rubber band at the end of the track, then release the vehicle.
8. Record the motion of the vehicles before and after collision takes place.
9. Develop the film to obtain the photograph of the collision process
10. Obtain the velocities of the vehicles before and after collision from the photographs.

3. Data Quantification

- Weigh the masses of vehicles used in the experiment
- Determine the length of the paper on the track as the reference scale for the length on the image. (D = ……. cm)
- Write down the frequency from the *strobo* lamp. (f = …… Hz)
- Measure the length of the image paper on the track.(d = ……… cm)
- Measure the traveled distance of the vehicle on the image before collision and its corresponding number of lines. (s = ……… cm and n = …)
- Determine the scale that will be used.
- Convert the distance on the image (before collision), with the real distance according to a specified scale (S = …………… m)
- Convert the number of lines into real time by multiplying it by the period of the strobo lamp. (t = (n-1).T)
- Repeat the procedure for the process after collision to obtain S_1' , S_2', t_1', and t_2' .
- Calculate the instantaneous velocities of the objects before and after the collision takes place using the equation:

$$v = \frac{S}{t} \qquad \text{………… (1)}$$

4. Data Analysis

Based on the above quantified data, then the initial and the final momentum could be calculated.

The initial momentum of system $= m_1 \mathbf{v_1} + m_2 \mathbf{v_2}$

The final momentum of system $= m_1 \mathbf{v_1'} + m_2 \mathbf{v_2'}$

Then the next steps are:

- Calculate the initial and the final momentum.

- Compare the initial momentum with the final momentum, are they remain the same or not.
- Calculate the difference between initial momentum and final momentum.
- Calculate the percent of accuracy from the result of initial and final momentum.

Due to considerably high degree of measurement uncertainties involved in the experiment, instead of using rigorous statistical test a simpler procedure to test the hypothesis will be used. The hypothesis will be accepted if the percentages of the comparative ration between the final and initial total momentum of the system are equal or more than 90%.

Data Analysis

For one dimensional collision there are only two directions involved in the calculation: right or left direction that can be represented by the sign plus or minus. Therefore, the vector notation of momentums and velocities may be dropped with provisions that the signs are consistently being used to represent the vector directions. In the following calculations, these assertions will be used.

The observed data presented in Appendix 1 - 4 can be summarized as follows:

Small vehicle *vs.* Small vehicle (vehicle a and vehicle b)

The result from the experiment small *vs.* small

Exp. Number	Scale (cm)	f (Hz)	vehicle	S (m)	t (s)	S' (m)	t' (s)	v (m/s)	v' (m/s)
1	1.15:10.7	3.292	a	0	0	0.051	0.304	0	0.168
			b	0.07	0.304	0.023	0.304	0.23	0.077
2	1.15:10.7	3.292	a	0	0	0.247	1.822	0	0.135
			b	0.056	0.304	0.023	0.304	0.184	0.061
3	0.7:10.7	3.334	a	0.107	0.299	0.046	0.299	0.357	0.155
			b	0	0	0.057	0.299	0	0.190
4	0.7:10.7	3.335	a	0.115	0.299	0.046	0.299	0.382	0.153
			b	0	0	0.061	0.299	0	0.204
5	0.7:10.7	3.335	a	0.107	0.298	0.046	0.299	0.357	0.153
			b	0	0	0.054	0.299	0	0.178

Using equation 2.3 and 2.7, and the masses of vehicles (m_a = 0.1672 kg, m_b = 0.1674 kg, m_A = 0.3648 kg and m_B = 0.3674 kg) as presented in Appendix 1 - 4, then the initial, final momentum, and the coefficients of restitution of each collision can be calculated as follows:

Experiment number 1.

Initial Momentum(p_i) = 0. 038452 kg m/s
Final Momentum(p_f) = 0. 040982 kg m/s
Percentage of accuracy = (p_i/p_f) x 100%
= 93. 82707%
Coefficient of restitution = 0. 4

Experiment number 2.

Initial Momentum(pi) = 0. 030762 kg m/s
Final Momentum(pf) = 0. 032871 kg m/s
Percentage of accuracy = (pi/pf)x100%
= 93. 58345%
Coefficient of restitution = 0. 4

Experiment number 3.

Initial Momentum(pi) = 0. 059645 kg m/s
Final Momentum(pf) = 0. 057695 kg m/s
Percentage of accuracy = (pf/pi)x100%
= 96. 73046%
Coefficient of restitution = 0. 1

Experiment number 4.

Initial Momentum(pi) = 0. 063926 kg m/s
Final Momentum(pf) = 0. 059705 kg m/s
Percentage of accuracy = (pf/pi) x100%
= 93. 39713%
Coefficient of restitution = 0. 133

Experiment number 5.

Initial Momentum(pi) = 0. 059664 kg m/s
Final Momentum(pf) = 0. 055438 kg m/s
Percentage of accuracy = (pf/pi) x 100%
= 92. 91695%
Coefficient of restitution = 0. 071429

Big vehicle *vs.* Big vehicle (vehicle *A* and vehicle *B*)

The result from the experiment big *vs.* big

Exp. Number	Scale (cm)	f (Hz)	vehicle	S (m)	t (s)	S' (m)	t' (s)	v (m/s)	v' (m/s)
1	0.7:10.7	3.32	A	0	0	0.684	3.313	0	0.206
			B	0.357	1.205	0.083	1.205	0.296	0.069
2	0.7:10.7	3.334	A	0	0	0.057	0.299	0	0.19
			B	0.071	0.299	0.014	0.299	0.238	0.048

Experiment number 1.

Initial Momentum(pi) = 0. 108763 kg m/s
Final Momentum(pf) = 0. 100646 kg m/s
Percentage of accuracy = (pf/pi) x 100%
= 92. 53707%
Coefficient of restitution = 0. 463636

Experiment number 2.

Initial Momentum(pi) = 0. 087374 kg m/s
Final Momentum(pf) = 0. 086879 kg m/s
Percentage of accuracy = (pf/pi) x 100%
= 99. 43386%
Coefficient of restitution = 0. 6

Small vehicle vs. Big vehicle (vehicle *a, b* and vehicle *A, B*), which small vehicle was at rest.

The result from the experiment small *vs.* big

Exp. Number	Scale (cm)	f (Hz)	vehicle	S (m)	t (s)	S' (m)	t' (s)	v (m/s)	v' (m/s)
1	1.15:10.7	3.292	A	0.084	0.304	0.414	2.43	0.276	0.17
			a	0	0	0.209	1.215	0	0.172
2	0.75:10.7	3.327	B	0.099	0.301	0.064	0.301	0.332	0.214
			b	0	0	0.064	0.301	0	0.214
3	0.75:10.7	3.334	B	0.079	0.299	0.049	0.299	0.262	0.166
			b	0	0	0.049	0.299	0	0.167
4	0.75:10.7	3.334	B	0.099	0.299	0.064	0.299	0.333	0.214
			b	0	0	0.071	0.299	0	0.238
5	0.75:10.7	3.334	B	0.099	0.299	0.071	0.299	0.333	0.238
			b	0	0	0.071	0.299	0	0.238

Experiment number 1.

Initial Momentum(pi) = 0. 100554 kg m/s
Final Momentum(pf) = 0. 090952 kg m/s
Percentage of accuracy = (pf/pi) x 100%
= 90. 45139%
Coefficient of restitution = 0. 006944

Experiment number 2.

Initial Momentum(pi) = 0. 122059 kg m/s
Final Momentum(pf) = 0. 114218 kg m/s
Percentage of accuracy = (pf/pi) x 100%

= 93. 57648%

Coefficient of restitution = 0

Experiment number 3.

Initial Momentum(pi) = 0. 096112 kg m/s

Final Momentum(pf) = 0. 089029 kg m/s

Percentage of accuracy = (pf/pi) x 100%

= 92. 63127%

Coefficient of restitution = 0

Experiment number 4.

Initial Momentum(pi) = 0.122324 kg m/s

Final Momentum(pf) = 0.118447 kg m/s

Percentage of accuracy = (pf/pi) x 100%

= 96.83101 %

Coefficient of restitution = 0.071429

Experiment number 5.

Initial Momentum(pi) = 0. 122324 kg m/s

Final Momentum(pf) = 0. 119223 kg m/s

Percentage of accuracy = (pf/pi) x 100%

= 96.17801%

Coefficient of restitution = 0

Big vehicle vs. small vehicle (vehicle *A, B* and vehicle *a, b*), which big vehicle was at rest.

The result from the experiment big *vs.* small

Exp. Number	Scale (cm)	f (Hz)	vehicle	S (m)	t (s)	S' (m)	t' (s)	v (m/s)	v' (m/s)
1	0.8:10.7	3.347	B	0	0	0.716	3.586	0	0.199
			b	0.12	0.299	0	0	0.403	0
2	0.8:10.7	3.356	B	0	0	0.421	2.384	0	0.177
			b	0.568	1.489	0	0	0.381	0
3	0.8:10.7	3.356	B	0	0	0.435	2.682	0	0.162
			b	0.522	1.489	0	0	0.35	0
4	0.8:10.7	3.356	B	0	0	0.482	2.384	0	0.202
			b	0.575	1.192	0	0	0.482	0
5	0.8:10.7	3.356	B	0	0	0.361	2.384	0	0.152
			b	0.495	1.489	0	0	0.332	0
6	0.8:10.7	3.356	B	0	0	0.502	2.384	0	0.21
			b	0.581	1.192	0	0	0.488	0
7	0.75:10.7	3.334	A	0	0	0.071	0.299	0	0.238
			a	0.157	0.299	0	0	0.523	0

Experiment number 1.

Initial Momentum(pi)	= 0. 067438 kg m/s
Final Momentum(pf)	= 0. 073319 kg m/s
Percentage of accuracy	= (pi/pf) x 100%
	= 91. 97849%
Coefficient of restitution	= 0. 49537

Experiment number 2.

Initial Momentum(pi)	= 0.063866 kg m/s
Final Momentum(pf)	= 0.064931 kg m/s
Percentage of accuracy	= (pi/pf) x 100%
	= 98.35913%
Coefficient of restitution	= 0.463235

Experiment number 3.

Initial Momentum(pi)	= 0.058606 kg m/s
Final Momentum(pf)	= 0.059549 kg m/s
Percentage of accuracy	= (pi/pf) x 100%
	= 98.41698%
Coefficient of restitution	= 0.462963

Experiment number 4.

Initial Momentum(pi)	= 0.080771 kg m/s
Final Momentum(pf)	= 0.074207 kg m/s
Percentage of accuracy	= (pf/pi) x 100%
	= 91.87297%
Coefficient of restitution	= 0.418605

Experiment number 5.

Initial Momentum (pi)	= 0.055601kg m/s
Final Momentum (pf)	= 0.055655 kg m/s
Percentage of accuracy	= (pi/pf) x 100%
	= 99.90201%
Coefficient of restitution	= 0.456081

Experiment number 6.

Initial Momentum (pi)	= 0.081711 kg m/s
Final Momentum (pf)	= 0.077299 kg m/s
Percentage of accuracy	= (pf/pi) x 100%
	= 94.601%
Coefficient of restitution	= 0.431034

Experiment number 7.

Initial Momentum(pi)	= 0. 087479 kg m/s
Final Momentum(pf)	= 0. 086756 kg m/s
Percentage of accuracy	= (pf/pi) x 100%
	= 99. 17355%

Coefficient of restitution = 0. 4545

The summary of the result can be listed as below:

The summary from the data's result

Type	Initial (kg m/s)	Final(kg m/s)	Accuracy (%)	Conclusion*
Small *vs.* Small	0. 038	0. 041	93. 827	HA
	0. 031	0. 033	93. 583	HA
	0. 060	0. 058	96. 730	HA
	0. 064	0. 060	93. 397	HA
	0. 060	0. 055	92. 917	HA
Big *vs.* Big	0. 109	0. 101	92. 537	HA
	0. 087	0. 087	99. 433	HA
Small *vs.* Big	0. 101	0. 091	90. 451	HA
	0. 122	0. 114	93. 576	HA
	0. 096	0. 090	92. 631	HA
	0. 122	0. 118	96. 831	HA
	0. 122	0. 119	96. 178	HA
Big *vs.* Small	0. 067	0. 073	91. 978	HA
	0. 059	0. 060	98. 417	HA
	0. 081	0. 074	91. 873	HA
	0. 056	0. 056	99. 902	HA
	0. 082	0. 077	94. 601	HA
	0. 087	0. 087	99. 173	HA

* HA : Hypothesis Accepted.

Conclusions and Suggestions

Conclusions:

- The percent of accuracy from the experiment to verify conservation law of momentum using Linear Air Track are up to 90%.
- Referring to the criteria of accepting the hypothesis given in the methodology (Chapter III), we may conclude that Linear Air Track can be used to verify the linear momentum conservation law on any collision between two objects.

Suggestions:

- The students should have to arrange the track to be horizontal, in order to get the accuracy data.
- Linear Air Track could be use for further research, to verify the kinetic energy that was lost in collisions.

References

Alonso, Marcelo., & Edward J.A. 1992. *Dasar - dasar Fisika Universitas*. Jakarta: Erlangga

Giancoli. 1995. *Physics*. USA: Prentice - Hall International Inc.

Griffin. 1981. *Linear Air Track: Force, Motion, Energy, Momentum and Collision.* England: Griffin and George Ltd.

Griffith, W. T. 2004. *The Physics of Everyday Phenomena*. New York: The McGraw-Griffith companies.

Henderson, Tom. 1996. *The Impulse-Momentum Change Theorem,* http:// www.glenbrook.k12.il.us/gbssci/Phys/Class/momentum/u4l1a.html (accessed on 31 Juli 2007)

Henderson, Tom. 1996. *The Law of Momentum Conservation,* http:// www.glenbrook.k12.il.us/gbssci/Phys/Class/momentum/u4l2b.htm l (accessed on 31 Juli 2007)

Inexus. 1999. *Translational Motions of a Mass Point,* http:// www.4science.net/main.asp??=item/item_view&item_idx=2189 (accessed on 31 Juli 2007)

Kamajaya. 2003. *Pintar Fisika 1*. Jakarta: Ganeca

Universitas Katolik Widya Mandala. 1998. *Pedoman Umum Penulisan Skripsi*. Surabaya: Universitas Katolik Widya Mandala

Wikipedia. 2007. *Momentum,* http://en.wikipedia.org/wiki/Momentum (accessed on 31 Juli 2007)

- - - - - - - gunting dan kirimkan ke alamat Tata Usaha FKIP atau fax. (031) 3891267 - - - - - - -

FORMULIR BERLANGGANAN JURNAL "MAGISTER SCIENTIAE"

Mohon dicatat sebagai pelanggan Jurnal "Magister Scientiae"

Nama : ____

Alamat : ____

____

(Kode Pos ______________________)

______________, ____________________

Harga langganan mulai Januari 2003 :

- Rp. 30.000,00 untuk 1 tahun
- Rp. 50.000,00 untuk 2 tahun
- Rp. 70.000,00 untuk 3 tahun

(______________________________)

Formulir Ini Boleh Difotokopi

BERITA PENGIRIMAN UANG LANGGANAN

Dengan ini saya kirimkan uang sebesar :

☐ Rp. 30.000,00 untuk langganan 1 tahun, mulai Nomor ………………. Tahun …………….

☐ Rp. 50.000,00 untuk langganan 2 tahun, mulai Nomor ………………. Tahun …………….

☐ Rp. 70.000,00 untuk langganan 3 tahun, mulai Nomor ………………. Tahun …………….

Uang tersebut telah saya kirimkan melalui :

☐ Bank "***Mandiri***", rekening Nomor **140 - 0002281773**, a/n Ig. Harjanto

☐ Pos Wesel dengan Resi nomor ……………………………….. tanggal …………………