Air Table Experimental Set

(Student's Guide)

PACKING LIST

1.   The Air Table

     1.1.   The Flat Plane

     1.2.   Spark Timer

     1.3.   Spark Timer Switches

     1.3.   Pucks

     1.4.   Compressor

     1.5.   Shooter

     1.6.   Carbon Paper

     1.7.   Foot Leveling Block

2.   Connection Cables:

     2.1.   Power Cable

     2.2.   Compressor Power Cable, 220V (AC)

     2.3.   Footswitch Cables for the Puck and Spark Timer

Purpose:

The main purpose of this experiment is to study and analyze:

I.   The position and velocity of the motion with **constant velocity**,

II.   The acceleration of a straight-line motion with **constant acceleration**,

III. Horizontal **projectile** (two-dimensional) motion of an object moving on an inclined air table,

IV.   Conservation of **linear momentum**.

Introduction to the Air Table

The air table consists of four main components: the flat plane, spark timer, pucks and compressor (Figure-**1**).

1. **The Flat Plane:** With a very smooth surface. Black carbon paper and white recording paper are placed on it (55x55 cm).

2. **Spark Timer:** It produces sparks with frequencies of 10,20,30,40 and 50Hz. In the experiments we select the frequency 10 or 20 Hz. This gives the best results.

3. **Pucks:** They are rigid heavy metal disks with very smooth surfaces. A hole is drilled at the center through which the pressured air flows. When the compressor is operated by pressing the pedal, the air with pressure flows through the holes of the puck and forms an air cushion between the two smooth surfaces: the plate of air table and smooth surface of the puck. Thus the pucks slide on the surface almost without any friction.

Figure-**1**: Air Table Product.

There is also an electrode at the bottom of the puck. When the spark timer is operated by pressing its switches, then high voltage produces sparks which causes dark spots on the white paper with equal time intervals.

If we place a piece of paper under the puck, we can record its trajectory by use of a spark apparatus, which leaves a trail of dots on the paper. The study of these dots enables us to measure the position as a function of time for the moving pucks.

	Flat Plane of the Air Table
	Spark Timer
	Compressor
	Foot Switches
	Shooter
	The Pucks
	Foot Leveler

Figure-**2**: Air Table Components.

4. **Compressor**: The compressor provides an air-flow through the cables to the pucks on the air table. When the compressor is switched on, an air-flow through the cables is produced from the compressor towards the pucks. The compressed air flowing through the bottom surface of the pucks reduces the friction between the pucks and the air table, and so the pucks move almost freely on the table.

To study air table experiments, first a sheet of carbon paper and then a sheet of white paper (as **experiment paper**) are placed on the air table. The puck moving on the surface of the air table will be considered as the particle. The pucks in the experiment are connected to the spark timer by conducting wires and then placed on the experiment paper on the air table. The spark timer works by means of a foot switch. While you are pressing the foot switch to start spark timer, sparks are produced continuously between the pucks and the carbon paper at a frequency (f) adjusted on the spark timer.

Each spark produces a dot on the experiment paper, and the motion of the pucks in any experiment can be examined using the path of these dots on the experiment paper. For example, if the frequency is set to $f = 20Hz$, each puck on the table marks 20 dots on the experiment paper in one second and the time interval Δt between successive dots is given by $T = 1/20 = 0.05$ second.

Air Table Experiments

Name	
Department	
Student No	
Date	

Experiment-1

Straight Line Motion with Constant Velocity

In this section of the experiment, you will study and calculate the velocity of an object moving in a straight line with constant velocity.

Theory

When a particle moves along a straight line, we can describe its position with respect to an origin (**0**), by means of a coordinate (such as x). If there is no net force acting on a moving object, it moves on a straight line with a constant velocity The particle's average velocity (v_{av}) during a time interval ($\Delta t = t_2 - t_1$) is equal to its displacement ($\Delta x = x_2 - x_1$) divided by Δt:

$$v_{av} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} \qquad (1)$$

From the Equation-(**1**), the average velocity is the displacement (Δx) divided by the time interval (Δt) during which the displacement occurs. If we plot a graph x versus t, then we will have a straight line with a slope. The slope of the line gives the average velocity of the motion.
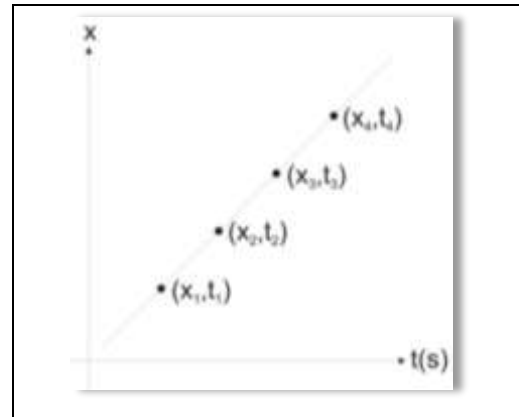
Figure-**3**: Position as a function of time.

For a displacement along the x-axis, the average velocity (v_{av}) of the object is equal to the slope of a line connecting the corresponding points on the graph of position versus time ($x - t\ graph$). The average velocity depends only on the total displacement (x) that occurs during the motion time (t). The position, $x(t)$ of an object moving in a straight line with constant velocity is given as a function of time as:

$$x(t) = x_0 + vt \qquad (2)$$

If the object is at the origin with the initial position $x_0 = 0$, the equation of the motion becomes at any time:

$$x(t) = vt \qquad (3)$$

So, the object travels equal distance in the equal time intervals along a straight line (Figure-**3**).

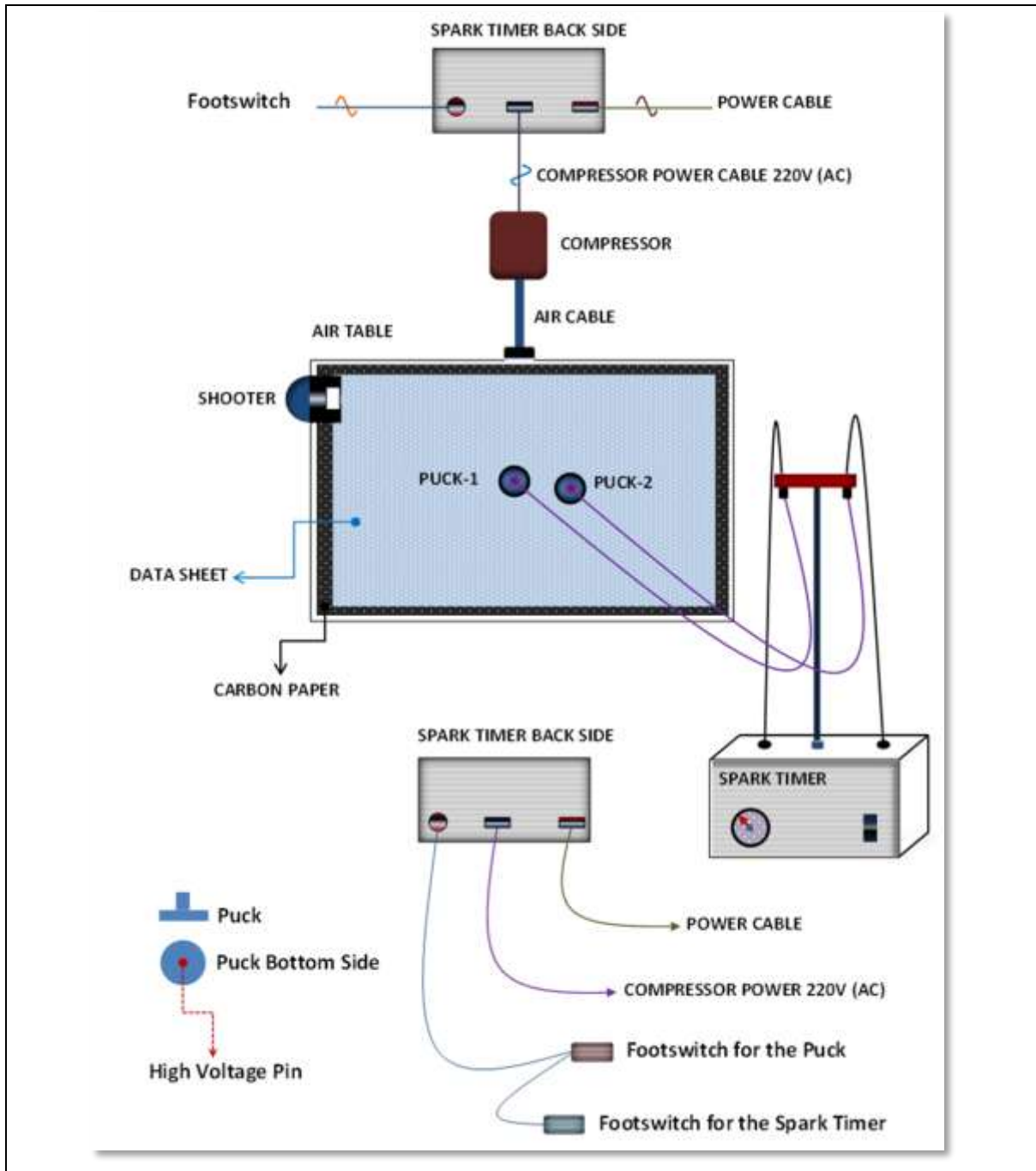Figure-**4**: The schematic representation of the experimental set-up with connection cables electrically connected to the air table.

Caution!

Do not touch any <u>metal or carbon paper</u> and also puck cable while spark timer is working. You may receive an electrical shock that is not dangerous but continues continuous exposure may be harmful.

Experimental Procedure

1. Level the air table glass plate **horizontally** by using the adjustable legs.
2. Place the black carbon paper (50x50 cm) which is semiconducting on the glass plate. The carbon paper should be flat and on the air table given by the experimental set-up (Figure-**4**).
3. Place white recording paper as data sheet on the flat carbon paper.
4. Place two pucks on white paper. Keep one of the pucks stationary on a folded piece of data sheet at one corner of the air table.
5. For **the alignment** of the air table, adjust the legs of the air table so that the puck will come to rest about the center of the table.
6. Test both two switches for the compressor and spark timer operations. With the puck pedal, the single puck should move easily, almost without friction when compressor works. When the spark timer foot switch is pressed, black dots on white paper should be observed (on the side that faces the carbon paper).
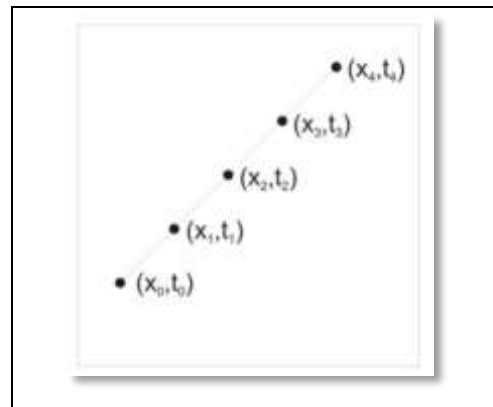

Figure-**5**: The dots produced by the puck on the data sheet.

7. Set the spark timer to $f = 20 Hz$.
8. Now again, test the compressor only by pressing the puck footswitch. Make sure that the puck is moving freely on the air table. By activating both the puck pedal and spark timer pedal (**foot switches**) in the same time, test also the spark timer and observe the black dots on the recording paper.
9. Place the puck at the edge of the table then press both compressor and spark timer pedals as you push the puck on the surface of air table. It will move along the whole diagonal distance across the air table in a straight line with constant velocity. Then, stop the pedals.
10. Remove the white recording paper from air table. The dots on the data sheet will look like those given in the Figure-(**5**).
11. Measure the distances of the dots starting from first dot by using a ruler.
12. Find also the time corresponding to each dot. The time between two dots is 1/20 seconds since the spark timer frequency was set to $f = 20 Hz$.

13. Number and **encircle** the dots starting from 0 at position x_0 (starting point) to avoid errors in calculations.

14. Measure the distances of the first 10 dots starting from dot "**0**". And then, find the time corresponding to each dot. Record the data values in the Table-(**1**). The time **interval between two dots** is given by $1/f$ which is equal to 1/20 seconds.

15. Using the data points in Table-(**1**), plot the $x - t \ graph$. The graph must show a linear function.

16. Draw the best line that fits a linear graph. Then, calculate the velocity of the puck by using the slope of the line.

17. From the values in Table-(**1**), calculate the position and time corresponding to each **dot interval** and then fill in your data in the Table-(**2**).

18. Calculate the average velocity (v_{av}) from the table for each dot interval and then compare with the value which is obtained from the graph.

Conclusions

- Compare the average velocity found from the graph with the velocity calculated for the each time interval?.

- Discuss the difference in the velocity values calculated from the table and the values found from the graph. Is the difference approximately the same?.

- What are the sources of error in the experiment?

- Write your comments related to the experiment.

LABORATORY REPORT

Table-1: Data values for the position and time of the motion with constant velocity.

Dot Number	Position $x \pm \Delta x \, (m)$	Time $t \, (\text{sec.})$	$v_{av} \, (m/s)$
			Slope
0	0	0	
1			
2			
3			
4			
5			......
6			
7			
8			
9			
10			

Table-2: Experimental data values for the average velocity of the motion with constant velocity.

Interval Number (n)	$x_n \, (m)$	$x_{n+1} \, (m)$	$x_{n+1} - x_n \, (m)$	$t_n \, (\text{sec.})$	$t_{n+1} \, (s)$	$t_{n+1} - t_n \, (s)$	$v \, (m/s)$
0-1	0	0	0	0	0		
1-2							
2-3							
3-4							
4-5							
5-6							
6-7							
7-8							
8-9							
9-10							

(Note that x_n is the position of the nth data point corresponding to the related dot).

Experiment-2

Straight Line Motion with a Constant Acceleration

In this part of the experiment, you will examine straight-line motion of an object (puck) with constant acceleration on an inclined frictionless air table. By plotting the experimental data, you will find the acceleration of the puck sliding down on an inclined air table.

Theory

When a particle slides straight down a frictionless inclined plane, its acceleration is constant, and it will move in a straight line down the plane. The magnitude of the acceleration depends on the angle at which the plane is inclined. If the inclination angle is 90^0, the object will slide down with an acceleration which is equal to the Earth's **gravitational acceleration** g with the magnitude of 9.8 m/s^2.

In this experiment, we will observe the motion of a puck moving in a straight line with a velocity changing uniformly. The back side of the air table is raised to form an inclined plane on the air table. The air table is inclined at an angle of θ with the horizontal plane as shown in the Figure-(**6**).

If you put the puck at the top of the inclined air table and let it slide down the plane, it will move downwards on a straight line but with increasing velocity. The rate of change of the velocity is the acceleration of the puck. If at time t_1, the puck is at the point x_1 with a velocity of v_1, then at a later time t_2, it will be at a point of x_2 with a velocity v_2.
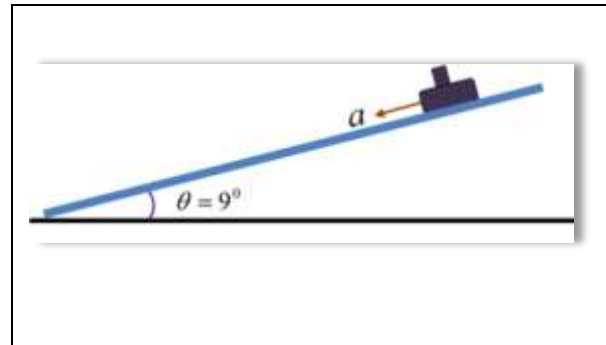

Figure-**6**: The straight down motion on an inclined air table.

The average acceleration of the puck in this time interval $\Delta t = t_2 - t_1$ is defined as:

$$a_{av} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} \qquad (4)$$

Suppose that at an initial time $t_1 = 0$, the puck is at the position of x_0 and has a velocity of $v_1 = v_0$. At a later time $t_2 = t$, it is in position x and has a velocity of $v_2 = v$. Then, the average acceleration will be equal to:

$$a_{av} = \frac{v - v_0}{t - 0} \qquad (5)$$

Then, the velocity of the puck will be:

$$v = v_0 + at \qquad (6)$$

If we consider the instantaneous acceleration (simply the acceleration) of the motion in the x-direction, it would be:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} \qquad (7)$$

The instantaneous acceleration in a straight line motion equals the instantaneous rate of **change of velocity** with time.

The equitation for an object's motion with constant acceleration in one dimension (x):

$$x = x_0 + v_0 t + \frac{1}{2} a t^2 \qquad (8)$$

where:

x_0: The displacement at time t = 0 (initial displacement),

v_0: The speed at time t = 0 (initial speed) and,

a: The object's acceleration.

If the motion of object starts from rest $(x_0 = 0,\ v_0 = 0)$ at $t = 0$, the object's position at any time t (instantaneous position) will be:

$$x = \frac{1}{2} a t^2 \qquad (9)$$

A graph of Equation-(**9**), that is, a $x - t \ \ graph$ for motion with constant acceleration, is always a parabola that passes through the origin in the $x - y$ plane. However, If a graph of $x - t^2$ is plotted, we find a straight line which has a **slope** of $"\frac{1}{2} a"$ and it will pass through the origin.

Experimental Procedure

1. To perform this experiment, first place a sheet of carbon paper and then a sheet of white paper on the air table.

2. Place the foot leveler to the upper leg of the air table to give an inclination angle (the angle with the horizontal plane) as $\theta = 9^0$. Use an angle finder to measure the inclination angle.

3. Put the puck at the top of the inclined plane and press the compressor pedal and check if the puck is falling freely.

4. Set the spark timer frequency to $f = 20 Hz$.

5. Put the puck at the top of the inclined plane to start the experiment. Press both puck and spark timer switches simultaneously and stop pressing when the puck reaches the bottom part of the inclined plane.

6. Remove the data recording paper from air table and examine the dots produced on it. Number and circle the dots from 0 to 10.

   6.1. Take the first dot as your initial data point $(x_0 = 0, t_0 = 0)$ and **the positive** $x - axis$ as direction of the puck's motion.

   6.2. Measure and record the time t and the positions x of the first 10 dots starting from "**0**". Record the data values in the data Table-(**3**) with respect to your initial point.

   6.3. Calculate and record also t^2 values in the Table-(**3**).

11

7. Plot x versus t^2. Then, draw the best line that fits your data points and using the slope of this line.

8. Determine the acceleration, a, of the puck. Show these calculations on your graph paper clearly.

   Note that $x = \dfrac{1}{2}at^2$ if $x_0 = 0$. Then, the slope of the $x \; versus \; t^2$ graph is equal to "$\dfrac{1}{2}a$".

Conclusions

- Determine the uncertainty in your measurement of displacements between dots on the data sheet?.

- What is the experimental value of the acceleration for the motion, in units of m/s^2?. Is the acceleration of the motion constant?.

Table-3: Experimental data values for the straight line motion with a constant acceleration.

Inclination Angle, θ (deg)	Frequency, f (Hz)	Dot Number	$x\,(m)$	t (sec)	$t^2\,(s^2)$	$a\,(m/s^2)$
			(Measured)			(By Slope)
		0	$x_0 = 0$	$t_0 = 0$	0	
		1				
		2				
		3				
		4				
…..	…..	5				…..
		6				
		7				
		8				
		9				
		10				

Experiment-3

Projectile Motion

Theory

The other type of the motion in this experiment is the horizontally **projected motion**. Projectile motion is the **two-dimensional** motion of an object under the influence of Earth's gravitational acceleration, g. The path followed by a projectile is called its **trajectory**.

The position of such an object at any given time t is given by a set of coordinates x and y which vary with respect to time and represent the horizontal and vertical coordinates, respectively. One of the two components of the velocity vector is parallel to the **horizontal** x-axis and the other is parallel to the **vertical**, or y-axis:

$$\vec{v} = v_x \hat{i} + v_y \hat{j} \tag{10}$$

The motion of the object in the horizontal x direction is a straight line motion with **constant velocity**. So, the x-component of the velocity (v_x) will be constant.

However, the acceleration only acts along the vertical direction. The x-component of acceleration is **zero** and y-component is **constant**. This means that only the vertical component of the velocity (v_y) will change with respect to time and the horizontal component of the velocity will be **constant**. Therefore, *we can analyze projectile (two-dimensional) motion as a combination of horizontal motion with constant velocity and the vertical motion with constant acceleration*.

We can express the vector relationships for the projectile's acceleration by separate equations for the horizontal and vertical components. The components of **the acceleration vector $\vec{a}$** are:

$$a_x = 0 \tag{11}$$

$$a_y = a \ (\textbf{Constant}) \tag{12}$$

In vector form, the acceleration can be expressed as the form:

$$\vec{a} = a_y \hat{j} \tag{13}$$

The position of the object at a given time is given by:

$$\vec{r} = x\hat{i} + y\hat{j} \tag{14}$$

For the two-dimensional (x, y) motion, we can separate acceleration (a), displacement (x) and velocity v in both x and y coordinate directions by the general equations below as:

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \tag{15}$$

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 \tag{16}$$

In order to model two-dimensional projectile motion, a metal puck will be set in motion on an air table. When the air compressor is switched on, the air is supplied to down the tube under the puck so that it moves with a given initial velocity on the frictionless plane.

Suppose that at time $t = 0$, the particle is at the point (x_0, y_0) and at this time its velocity components have the initial v_{0x} and v_{0y}. Since the velocity of **horizontal motion** in the projectile motion is constant, we find:

$$a_x = 0 \qquad (17)$$

$$v_x = v_{0x} \qquad (18)$$

$$x = x_0 + v_x t \qquad (19)$$

If we take the initial position $(at\ t = 0)$ as the origin, then:

$$x_0 = y_0 = 0 \qquad (20)$$

Using this relationship in the Equation-(**19**), we will find the equation of motion along the $x - axis$ as:

$$\boxed{x = v_x t} \qquad (21)$$

For the motion along the $y - axis$, the velocity (v_y) at the later time, t becomes:

$$v_y = at \qquad (22)$$

$$\boxed{y = \frac{1}{2}at^2} \qquad (23)$$

The dots produced on the data sheet will look like the figure as shown in the Figure-(**7**). Here, note that the intervals between the dots of the x-projections in the horizontal direction are equal.
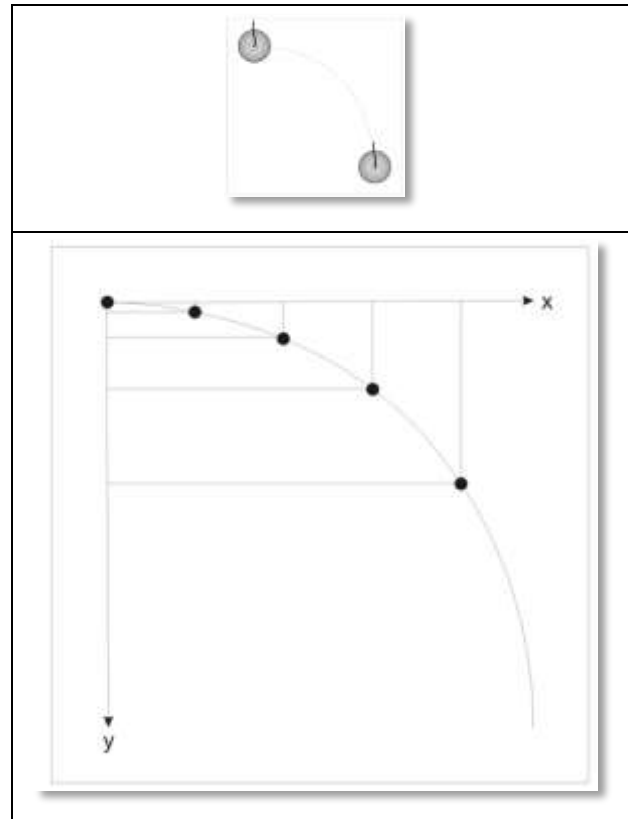

Figure-**7**: Schematic diagram of the horizontally projected motion of the puck on an inclined air table.

The projectile motion has a constant *horizontal velocity* and a constant *vertical (downward) acceleration* due to gravity. The *vertical distance* (y) caused by the change in the velocity is given by Equation-(**23**). Finally, if you analyze the projectile motion, you can make the following important conclusions:

- The horizontal component $(x - axis)$ of a projectile's **velocity** is constant. (So, the horizontal component of acceleration, in other words, is zero).

- The projectile motion will have a constant downward $(y - axis)$ **acceleration** due to gravity as seen in the Figure-(**7**).

Experimental Procedure

1. Place the foot leveling block at the upper leg of the air table to give the plane an inclination angle of $\theta = 9^0$.

2. Adjust the frequency of the spark timer, $f = 20Hz$.

3. Keep one of the pucks stationary on a folded piece of data sheet paper and carbon paper at the lower corner of the plane.

4. Attach the shooter to the upper left side of the table with 0^0 (zero degrees) **shooting angle** to give horizontal shooting.

5. Make test shootings to find the best tension of the rubber to give a convenient trajectory.

6. First activate the compressor pedal and as you release the puck from the shooter also start the spark timer by pressing its pedal. Stop pressing both pedals when pucks reach the bottom of the plane. These dots are the data points of the trajectory-A.

7. Now, place the puck opposite to the shooter without tension of shooter (note that the puck must be outside the shooter). Then activate both compressor pedal and spark timer pedal in the same time and then let it slide freely down on the inclined plane. The dots will give trajectory-A.

8. Remove the data sheet and examine the dots of trajectory. You must get the trajectories illustrated in Figure-(**8**). If the data points are inconvenient to analyze, repeat the experiment and get new data.
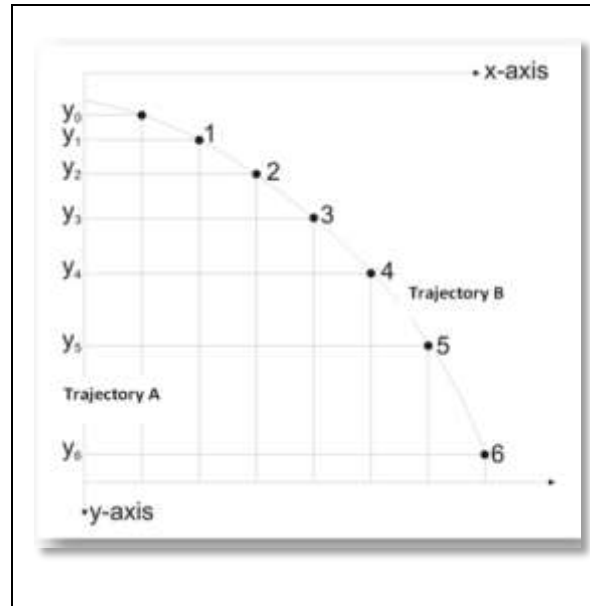

Figure-**8**: The dots as data points produced by the puck on the data sheet.

9. Select a clear dot on the path as the initial position of the motion as $y = 0$ and $t = 0$.

   9.1. Circle and number the data points (dots starting from the first dot as **0**) as 0, **1**, 2, 3, 4, 5…**10** as shown in the Figure-(**8**).

   9.2. Consider the downward trajectory as positive $y - axis$ and horizontal projection as positive $x - axis$.

10. Draw perpendicular lines from dots to $x \; and \; y - axis$ for the trajectory-B by taking the **first dot** (dot 0) as the origin $(0, 0)$. This origin is the initial position of the projectile motion.

11. Measure the horizontal $x(m)$ and vertical $y(m)$ displacements from the initial position $(0, 0)$ and then record in the experimental data tables.

12. Determine the time (t) for each of these dots. The time interval **between two dots** is given by $1/f$ which is equal to 1/20 seconds. Then, calculate total time of flight (t_f) corresponding to the total horizontal displacement (x_R) of a projectile.

13. Calculate and record the horizontal velocity (v_x) by using **the time of flight** (t_f) and the total horizontal distance traveled during the motion (x_R). Complete the data Table-(**4**).

14. Starting from dot "0" of the trajectory-**B**, measure the distances of the y projections (**y-axis**) of the first 10 data points (dots). Determine also the times corresponding to each of these dots.

    14.1. Fill the measurements in the **trajectory-B** columns in the experimental data Table-(**5**).

15. Similarly, by starting from dot "0" of the trajectory-**A**, measure the distances of the y-projections of the first 10 data points (dots).

    15.1. Calculate the times corresponding to each of the dots for trajectory-**A**.

    15.2. Record your data values in the **trajectory-A** columns in the Table-(**5**).

16. Using the equation $y = \dfrac{1}{2}at^2$, find the accelerations a_A and a_B of the **vertical** motions for both trajectory-**A** and **B**. In the calculations, take displacement-y as the total distance of the first 10 dots starting from the dot-0 on the $y-axis$.

17. Compare these two accelerations of both trajectories and also compare them with the acceleration found in the previous experiment (Part-A).

Comments and Discussion:

Path 1 (straight line-trajectory-**A**):

- Is the acceleration constant for the motion along the axis?

Path 2 (curved line- trajectory-**B**):

- Is the **horizontal velocity** of a projected puck constant? Use your graph and data sheet for your explanation.
- What is the **horizontal acceleration** of a projected puck?.
- Does the **vertical velocity** of the object increase downward in each time interval?.
- Is the **vertical acceleration** of projectile (two-dimensional) motion constant?.

LABORATORY REPORT

Table-4: Horizontal velocity of the projectile motion.

Frequency, f (Hz)	Dot Number	Trajectory-B (x-Horizontal Component Motion)				
		$x(m)$	t (sec)	x_R (m)	t_f (sec)	v_x (m/s)
		(Measured)	(Measured)	(Calculated)	(Calculated)	(Calculated)
20	0	0	0			
	1					
	2					
	3					
	4					
	5			…..	…..	…..
	6					
	7					
	8					
	9					
	10					

Table-5: The measurements of accelerations for the trajectory-A and trajectory-B.

Dot Number	Trajectory-A		Trajectory-B		Trajectory-A	Trajectory-B
	(Vertical Motion)		(Vertical Motion)		$(By\ the\ Slope)$	$(By\ the\ Slope)$
	$y(m)$	t (sec)	$y(m)$	t (sec)	$a_A\ (m/s^2)$	$a_B\ (m/s^2)$
0	0	0	0	0	0	0
1						
2						
3						
4						
5					…..	…..
6						
7						
8						
9						
10						

Experiment-4

Conservation of Linear Momentum

Theory

If we consider a particle of constant mass, m, we can write Newton's second law for this particle as:

$$\Sigma \vec{F} = m\frac{d\vec{v}}{dt} = \frac{d}{dt}(m\vec{v}) \qquad (24)$$

Thus, Newton's second law says that the net force acting on a particle equals to the time rate change of the combination, $m\vec{v}$ (the product of the particle's mass and velocity). This combination is called as the momentum or **linear momentum** of the particle. Using the symbol $\vec{p}$ for the momentum, we get the definition of the momentum:

$$\vec{p} = m\vec{v} \qquad (25)$$

If we substitute the definition of momentum into the Equation-(**24**), we get *Newton's second law in terms of momentum*:

$$\Sigma \vec{F} = \frac{d\vec{p}}{dt} \qquad (26)$$

According to Equation-(**26**), the net force (vector sum of all the forces) acting on a particle equals to the time rate change of the particle's momentum. Since momentum is a vector quantity with the same direction as the particle's velocity, we must express the momentum of a particle in terms of its components.

If the particle has the velocity components of (v_x, v_y), then its momentum components will be (p_x, p_y). Then, the components of momentum are given by:

$$p_x = mv_x \qquad (27)$$

$$p_y = mv_y \qquad (28)$$

If there are no external forces (the net external force on a system is zero), the total momentum of the system, $\vec{P}$ (the **vector sum** of the momentum of the individual particles that make up the system) is constant or conserved. Each components of the total momentum is separately conserved. Remember that in **any collision** in which external forces can be neglected, momentum is conserved and the total momentum before equals to the total momentum after. **Only** in **elastic collisions**, the total kinetic energy before equals to the total the kinetic energy after. So, in an elastic collision between two bodies, the initial and final relative velocities have the same magnitude.

For a system with the two pucks, the total momentum (P_t) before the collision will be the same as the total momentum after the collision if the friction can be ignored.

By denoting initial momentums by the subscript "i" and final momentums by the "f", **the vector equation** for the principle of the conservation of momentum is given by:

$$\vec{P}_{t,i} = \vec{P}_{t,f} \qquad (29)$$

$$\vec{P}_{1,i} + \vec{P}_{2,i} = \vec{P}_{1,f} + \vec{P}_{2,f} \qquad (30)$$

Let the velocities of the two pucks be denoted $v_{1,i}$ and $v_{2,i}$ before the collision as the **initial** values and let the velocities after the collision be $v_{1,f}$ and $v_{2,f}$ as the **final** values.

Then, **the magnitude** of the momentum of the each puck before and after the collision will be:

$$P_{1,i} = mv_{1,i} \qquad (31)$$

$$P_{2,i} = mv_{2,i} \qquad (32)$$

$$P_{1,f} = mv_{1,f} \qquad (33)$$

$$P_{2,f} = mv_{2,f} \qquad (34)$$

In the any experiment, if we analyze the initial and final velocities of a system with the two particles (puck-A and B), we get:

$$m_1\vec{v}_{1,i} + m_2\vec{v}_{2,i} = m_1\vec{v}_{1,f} + m_2\vec{v}_{2,f} \qquad (35)$$

where,

$v_{1,i}$: The velocity of puck-A before collision,

$v_{2,i}$: The velocity of puck-B before collision,

$v_{1,f}$: Final velocity of puck-A after collision,

$v_{2,f}$: Final velocity of puck-B after collision.

When the masses of the two pucks are equal $(m = m_1 = m_2)$, conservation of the momentum gives the velocity vector relationship:

$$\vec{v}_{1,i} + \vec{v}_{2,i} = \vec{v}_{1,f} + \vec{v}_{2,f} \qquad (36)$$

Equations-(**35**) and (**36**) explain that the magnitude of the momentum will remain the same. The directions and velocities of the individual pucks may change, but **vector sum** $(\vec{v}_{1,i} + \vec{v}_{2,i})$ of their momentums will remain constant (**total momentum is conserved**).

Since the time interval (Δt) is constant between the successive dots on the data sheet produced by each puck, the distance between two adjacent points on the trajectory of a puck will be proportional to the velocity (v). So, in a given experiment, the task of measuring the velocities of the two pucks reduces to that of measuring distances (x) of the dots.
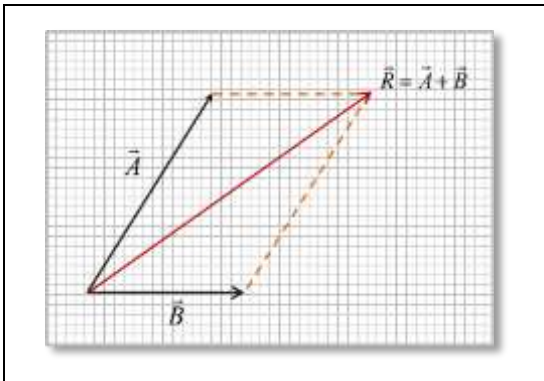
Figure-**9**: The way to add two vectors by a parallelogram.

The momentum is a vector quantity, so we need to add two velocity vectors and to represent the magnitude of the velocity vector. Note that:

- The **magnitude** of a given vector in a scaled vector diagram is depicted by the length of the arrow.
- The arrow is drawn a precise length according to a chosen scale and should have has an obvious arrowhead.

For example, we have **a velocity vector** with a magnitude of $20cm/s$. Then, if the scale used for constructing the diagram is chosen to be $1cm = 5cm/s$, the **vector arrow** of the velocity vector is drawn with a length of $4cm$, such that: $4cm \times [(5cm/s)/1cm] = 20cm/s$.

Therefore, graphical techniques of vector addition involve drawing accurate scale diagrams to denote individual vectors and their resultants. The parallelogram method is a graphical technique of finding the resultant of two vectors.

The way to add two velocity vectors $(\vec{A} = \vec{v}_{1,i} \ and \ \vec{B} = v_{2,i})$ is to construct a parallelogram as shown geometrically in the Figure-(**9**). According to the parallelogram law, if two vector quantities are represented by two adjacent sides or a parallelogram, then the diagonal of the parallelogram will be equal to the resultant vector (vector sum), $\vec{R}$ of these two vectors. The resultant is the diagonal of the parallelogram. The magnitude can be determined from the length of its arrow.

To find the sum of the two vectors geometrically, place vectors of $\vec{A}$ and $\vec{B}$ such that their initial points **coincide**. After that, complete a parallelogram that has $\vec{A}$ and $\vec{B}$ as two sides. **The diagonal of the parallelogram** with the same initial points as $\vec{A}$ and $\vec{B}$ is the sum of $\vec{A} + \vec{B}$. The **vector sum** $\vec{A} + \vec{B}$ is called the resultant of vectors $\vec{A}$ and $\vec{B}$.

Experimental Procedure

This experiment will be carried on a level air table. We will investigate the conservation of momentum for two pucks moving on frictionless horizontal air table and we will assume there is no net **external force** on the system. The two pucks will be allowed to collide and then their total momentum before and after the collision will be measured.

1. By adjusting the legs of the air table, make sure it is precisely leveled.
2. Choose the spark timer frequency as $f = 20Hz$.
3. Activate the compressor and spark timer switches in the same time, and then push the two pucks diagonally to get a collision nearly at the center of the table. Don't push too slowly or too fast, you will find the best speed after several experimental test observations.
4. Release the two switches when they complete their motion after the collision.
5. Remove the data sheet on the air table.
   5.1. Number the dots produced by each puck starting as 0, 1, 2, 3, 4, 5…10.
   5.2. Label the two trajectories produced by the pucks as A and B before the collision and then A' and B' after the collision. The dots of the two pucks should look like those in the Figure-(**10**).
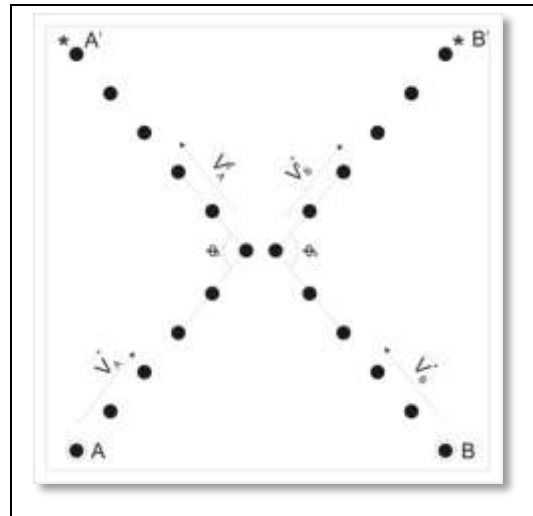

Figure-**10**: The motion of the two pucks before and after the collision.

6. Measure the total length of the two or three intervals of the each trajectory before and after the collision with a ruler.
7. Find the corresponding total time (t) of the two or three intervals by taking the spark timer frequency $f = 20Hz$.
8. Calculate the **magnitude** of velocity ($v = |\vec{v}|$) for each puck-A and B before and after the collision. The magnitude of velocity of the each puck is found by using the total length dividing by total time (t). Fill your calculated data values in the Table-(**6**).
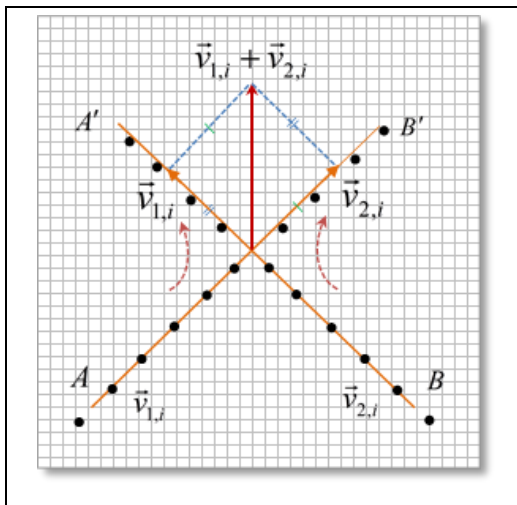
Figure-**11**: Vector sum given geometrically by constructing a parallelogram.

9. Find the **vector sum** $\vec{v}_{1,i} + \vec{v}_{2,i}$.

    9.1. To find vector sum $\vec{v}_{1,i} + \vec{v}_{2,i}$, extend the trajectories A and B until they intersect on the data sheet as seen in the Figure-(**11**).

    9.2. By starting from the intersection point, draw the corresponding velocity vectors of $\vec{v}_{1,i}$ and $\vec{v}_{2,i}$ along the directions with lengths proportional to the **magnitudes** of these velocities $\left|\vec{v}_{1,i}\right|$ and $\left|\vec{v}_{2,i}\right|$.

    9.3. Draw a $1cm$ vector to represent a **velocity** of $\left|\hat{v}\right| = 10cm/s$ on your data sheet or on a graph paper such that **scale: 1cm=10cm/s**.

9.4. Constructing the parallelogram as shown in the Figure-(**11**), add the two velocity vectors by using parallelogram method to find the vector sum (**resultant vector**) $\vec{v}_{1,i} + \vec{v}_{2,i}$ and its magnitude as $\left|\vec{v}_{1,i} + \vec{v}_{2,i}\right|$. Record the results in the Table-(**6**).

9.5. The **length** of the each vector represents the magnitude and it points in the direction of the velocity.

10. Repeat the same procedure to find the vector sum of $\vec{v}_{1,f} + \vec{v}_{2,f}$ and the corresponding magnitude.

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Table-6: Conservation of the linear momentum.

$v_{1,i}\ (m/s)$	
$v_{2,i}\ (m/s)$	
$\left|\vec{v}_{1,i} + \vec{v}_{2,i}\right|$	
$\left|\vec{v}_{1,f} + \vec{v}_{2,f}\right|$	

Comments and Discussion:

1. Is the linear momentum is conserved in the collision if no external force acts on the system?.
2. Discuss the conservation of the linear momentum by using the data values.