PHYS-101 LAB-02

One- and Two-dimensional Motion

1. Objective

The objectives of this experiment are:

- to measure the acceleration of gravity using one-dimensional motion
- to demonstrate the independence of motion along two perpendicular axes in projectile motion

2. Theory

A. One-Dimensional Motion. When an object is released ($v_{yo} = 0$) subject only to the earth's gravitational field, it moves with constant acceleration towards the center of the earth. This free-fall motion is an example of uniformly accelerated one-dimensional (1D) motion. The object's velocity vs. time curve is a straight line with slope g and its displacement vs. time curve must be quadratic in time t. The kinematical equations that govern its motion are (assuming upward motion is "positive"):

$$y = y_o + v_{yo}t - \frac{1}{2} gt^2$$
$$v_y = v_{yo} - gt$$
$$a_y = - g$$

B. **Two-Dimensional Motion**. If the same object is launched at an angle θ above the horizontal, the resulting **two-dimensional motion can be resolved into two *independent* motions**: accelerated motion along the vertical and uniform motion (constant velocity) along the horizontal. We summarize our description of projectile motion:

Free Fall Motion Along the y-axis:

$$y = v_{yo}t - \frac{1}{2} gt^2$$
$$v_y = v_{yo} - gt$$
$$a_y = - g$$

Uniform Motion Along the x-axis

$$x = v_{xo}t$$
$$v_{xo} = \text{constant}$$
$$a_x = 0$$

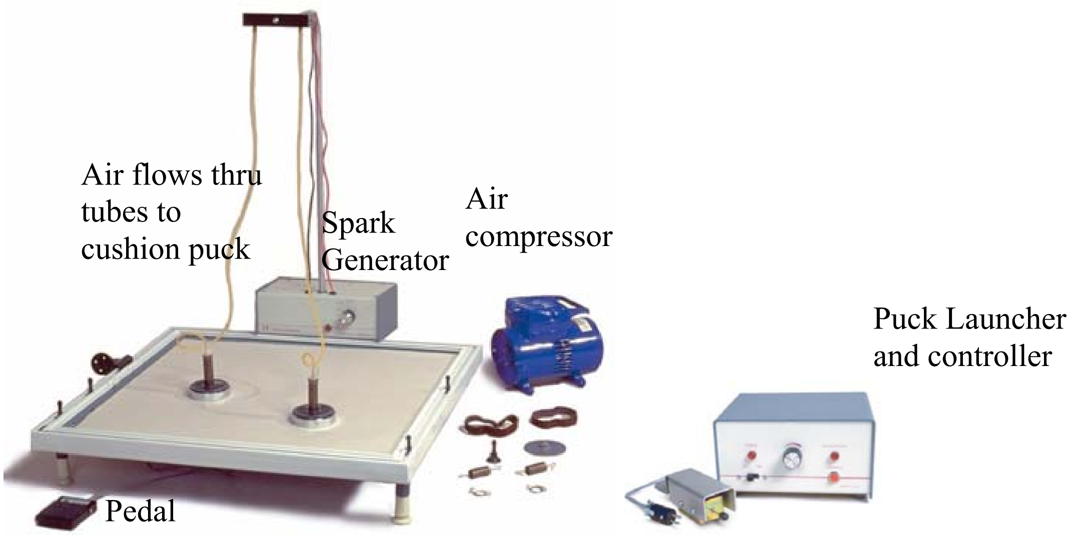
where $v_{xo} = v_o \cos \theta$ and $v_y = v_o \sin \theta$.

3. Experimental Details

The first part of the experiment ***indirectly*** determines the acceleration due to gravity g by measuring the acceleration of an air-cushioned puck ***sliding down*** an inclined airtable. To reduce the damping effects of friction, this experiment uses pucks that move over a cushion of air provided by an air compressor and plastic tubing through its center. Since the table is inclined at an angle φ, the puck's acceleration along the incline should be a = gsin φ (see Pre-lab). The underside of the puck sparks at its center point and burns a tiny dot at a pre-determined frequency. From these marks, displacement measurements can be made and the resulting velocity and acceleration calculated. Finally, this is used to calculate the experimental "g" from the expression a = gsin φ, obtained from your Pre-Lab.

To study projectile (two-dimensional) motion, the puck is launched at an angle θ using a puck "launcher" which has a solenoid that suddenly expands when a capacitor is discharged by a switch. The x- and y- components of the displacement and velocity vectors are experimentally obtained from the spark marks left by the puck. The vertical (y) component of the velocity is obtained and used to experimentally determine the acceleration along the y-axis. The horizontal (x) component of the velocity for each position is measured.

3.1 Apparatus



Air Table with 3 air pucks (2 x 500 g, 1 x 250 g), Puck Launcher, Air compressor, Ruler, Protractor

3.2 Experimental Procedure

A. Collecting Data for Measurement of "g"

1. Lay down the sheet of carbon paper provided on the air table. On top of this put a new sheet of white paper provided. Since you you will use only 1 puck for this experiment, set aside the other puck on a corner of the airtable. Plug in the air compressor power cord to begin supplying air used to cushion the pucks. Notice that the air puck now moves relatively freely along the surface. Check with your Lab TA

if the air table has already been pre-aligned for you (In most cases, this has been done so there is no need to further incline the table.) Otherwise, incline the air table at an angle that is somewhere between 5° and 10° with respect to the horizontal, as measured approximately by a protractor.

2. Set the frequency of the spark generator to f = 10 Hz (makes a mark every 1/10 second). Position a puck at the raised end of the airtable, preferably close to the middle, and release it in such a way that it traverses a straight line. Adjust the airtable until you are satisfied with its motion. Once satisfied, determine more accurately the angle of the incline by measuring its rise Δy and run Δx. And using $\tan\theta = \Delta y/\Delta x$.

3. Turn on the spark timer. Release the puck from the same height and immediately press the spark generator's control pedal to energize the launch the puck. **IMPORTANT / DANGER:** ***Avoid touching the metallic sections of the puck while pressing on the charging pedal or you might receive an uncomfortable ELECTRIC SHOCK***. After the marks are made on the sheet, STEP OFF the energizing pedal. ***DO NOT touch the metallic parts of the pucks while the pedal is depressed.***

4. If all went well, you will have obtained a straight line of marks which are increasingly spaced apart. (It might look like something below) Repeat this experiment until this result is obtained. Keep this sheet of paper containing your "data". Proceed to Step 5 (You will process this 1D-motion data in Step 7).

B. Collecting Data for Measurement of Projectile Motion

5. Get a new sheet of paper. Position and clamp down the puck launcher at one of the bottom corners of the inclined airtable. Point it "upwards" towards the raised end of the airtable at some convenient angle measured by a protractor. Switch on the launcher controller box. After charging it to a specified setting, press the Launch Button on the controller box. If all went well, you will have observed a parabolic path. If not, you can adjust the puck launcher accordingly. (If necessary, you can adjust the airtable's tilt, but consult first with your TA. Remember to record the final angles of the airtable's tilt and that of the launcher.)

6. To collect data, switch on the spark timer by stepping on the pedal and launch the puck. ***Remember to follow the Safety Precautions in Step 2 to avoid being shocked.*** After obtaining a good set of points, turn off all power (launcher controller, spark timer and air compressor). Keep the white paper where all the spark marks are on and proceed to Part C to process data.

KEEP EVERYTHING ABOVE THIS LINE. SUBMIT EVERYTHING BELOW THIS LINE.

LAB-02 One- and Two-Dimensional Motion DATA

Name:________________________ Sec./Group__________ Date:_____________

Table 1. 1D Motion Data **frequency f = ______ Hz**

Δy = ________cm Δx = ________cm Angle of Incline = _____°

Distance Between 8 Successive Marks (mm)	Average Velocity between Marks (mm/s)
(1)	
(2)	
(3)	
(4)	
(5)	
(6)	
(7)	

Table 2. 2D (Projectile) Motion Data: "y-component" **frequency f = ______ Hz**

Δy = ________cm Δx = ________cm Angle of Incline = _____°

Angle of Launcher = _____°

Distance Between 8 Successive Marks (mm)	Average Velocity between Marks (mm/s)
(1)	
(2)	
(3)	
(4)	
(5)	
(6)	
(7)	

Table 3. 2D (Projectile) Motion Data: "x-component"

Distance between 8 Successive Marks (mm)	Average Velocity between Marks (mm/s)
(1)	
(2)	
(3)	
(4)	
(5)	
(6)	
(7)	

C. Analysis of Data

7. Using a ruler, measure in millimeters the distance between 8 successive marks. Record this on the table provided (Table 1). Divide each distance by the period T = 1/f of the spark timer to obtain the average speed of the puck between each pair of marks. Record this on the column marked Average Speed <v> in units of mm/sec.

Open **Microsoft Excel** on your Computer. Enter the speeds as a function of time. Enter time in the first column and the average speeds on the second column. Plot these average speeds (mm/s) as a function of time (s) and extract a best fit (straight) line. You can do this by highlighting both columns and clicking "Insert…. Chart…(select XY Scatter)" on the Menu Toolbar. When a graph is generated, right-click on the data points, and select "Add Trendline", choosing the "Linear" option; click on Options on the Add Trendline Window and check the options "Display equation on chart". Print out a graph for each member of your group and enclose these to your Lab Write-ups.

Extract the slope from the equation of the best-fit line, in units of mm/sec^2. Using your Pre-Lab calculations, ***determine the experimental value of the acceleration g due to gravity, in units of m/s^2. Compare this with 9.8 m/s^2 and obtain a percentage difference as defined by:***

% difference = [(expt'l. value – theor. value)/theor. value] x 100%

8. To process the data for the vertical component of the projectile motion, measure in mm the distance between 8 successive marks along the "y-axis" of the air table. Record this on the table provided (Table 2). Using the same procedure in Step 6, record the average speeds along the y-axis, plot these as a function of time (secs) and obtain the slope of a best fit (straight line), in units of mm/sec^2. Print out a graph for each member of your group and enclose these to your Lab Write-ups. ***Calculate the corresponding acceleration "g" due to gravity. What is its percentage difference, relative to g = 9.8m/s^2?***

Why is the "g" determined using "projectile motion" data particularly close to the value determined from the "free-fall" data in Step 7 ?

9. To process the data for the horizontal component of the projectile motion, measure in mm the distance between 8 successive marks along the “x-axis” of the air table. Record these on the table provided (Table 3). Plot these speeds as a function of time and draw a best-fit line. Print out a graph for each member of your group and enclose these to your Lab Write-ups. ***What is the average speed in mm/s? What is the slope of this line ? Explain why this number should be small.***

Determine the initial launch velocity of the puck.

D. Error Estimate

10. What is the uncertainty in your measurement of displacements between marks ?

11. What is the uncertainty in your measurement of angles ?

12. What is the maximum uncertainty in your measurement of “g” ? Compare this with your results and explain any discrepancies. Are there any other sources of systematic errors in your procedure that you should take into account ?

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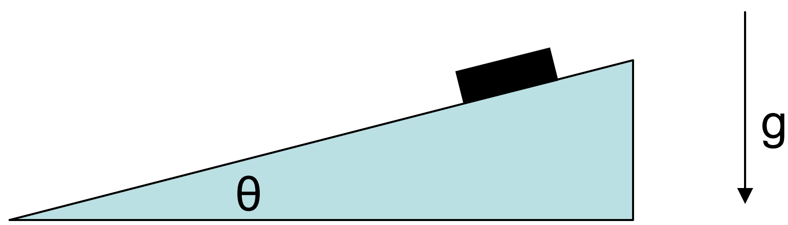
Name:________________________ Sec./Group__________ Date:_____________

4. Pre-Lab

1. Determine the acceleration of a particle down a smooth plane, inclined at an angle θ with respect to the horizontal. Draw acceleration vectors on the following diagram.



2. A particle is launched in a gravitational field g with an initial velocity $\mathbf{v_o}$ at an angle of θ with respect to the horizontal.

   a. Write down the equations for displacements along x and along y, as a function of time t.

   b. Combine these equations to eliminate time t and **explicitly** show that the resulting equation of the form y = f(x) shows that the trajectory is ***parabolic***.

5. JUST FOR THE FUN OF IT: Falling without Air Friction

In the lab, you will find a clear tubing that has been *evacuated* by a pump. Inside the tubing, there is a feather and a coin. Demonstrate to yourself that when the tube is evacuated, that the feather and coin falls at the same rate. Do this several times since the feather's extended body may rub against the walls of the tubing.

Perform the hands-on Projectile/Free-Fall Motion Demonstration. In this demonstration, at the same time a ball is launched horizontally, a second ball is made to vertically fall from the same height. Experimentally determine whether the two reach the bottom in the same time. What does this show ?