PHYS101 EXPERIMENT 2. VELOCITY AND ACCELERATION

Objective:

The purpose of this experiment is to study the motion with constant velocity and constant acceleration.

Introduction:

Mechanics is the study of the motion of objects and their interaction as comprehended by basic physical principles. Whereas classical mechanics, or Newtonian mechanics, deals with objects the size of which is large compared with that of the atom and that move at speeds far less than that of light, quantum mechanics, or wave mechanics, is the basis for understanding atomic and subatomic phenomena, and relativistic mechanics concerns high-speed phenomena.

Kinematics is an abstract study of motion that aims to provide a description of the spatial position of points in moving bodies, the rates at which the points are moving (velocity), and the rate at which their velocity is changing (acceleration).

For a point moving in a straight path, a list of corresponding positions and times would constitute a suitable scheme for describing the motion of the point. A continuous description would require either a graphical plot or a mathematical formula expressing position in terms of time.

Newton's three laws are the basic postulates (self-evident truths) governing the relations between the forces acting on a body and the motion of the body. Although they were formulated for the first time in usable form by Newton, they had been discovered experimentally by Galileo about four years before Newton was born. The laws cover only the overall motion of a body, i.e., the motion of its center of mass - and not any rigid body motion such as rotation. This is equivalent to assuming that the body is a particle.

According to Newton's first law, an object set in motion on a perfectly smooth, leveled, frictionless surface continues to move in a straight line with constant velocity. According to Newton's second law, when a force is applied to an object, the object experiences an acceleration proportional in magnitude to that of the applied force. This relationship is usually expressed as

$$\sum \vec{\boldsymbol{F}} = m\,\vec{\boldsymbol{a}}$$

in which $\sum$, the symbol for summation, indicates that if more than one force acts on the object, the vector sum of the forces must be used. In this experiment the all forces will assumed to be constant, that is they will not vary with time. A simple example of providing an accelerating force on an object is to tilt the surface over which the object rests; the acceleration a may then be predicted from the angle of tilt, and it may also be determined experimentally from measurements of the positions of the object at successive time intervals. Theoretically, the position $x(t)$ is given by the equation

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

where x_0 is the initial position, v_0 is the initial speed and a is the acceleration.

In this experiment we shall consider the motion of a puck along a straight path on an air table. The position of the puck is described at any instant by giving its distance from some reference point on the air table. We call this distance x, clearly it varies with time (t) when the puck moves, so x is a function of t.

Average and instantaneous velocities: The average velocity during a time interval between t_1 and t_2 in which the displacement has changed from x_1 to x_2 is defined as

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1}$$

The instantaneous velocity is thought of as the value of the average velocity when the time interval becomes extremely short, that is to find the value which v approaches as Δt approaches to zero. This is called the *limit* of v as $\Delta t \to 0$ and is the mathematical definition of the instantaneous velocity.

$$v = \lim_{t_2 \to t_1} \frac{x_2 - x_1}{t_2 - t_1} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

This expression is also called the derivative of *x* with respect to *t.*

Numerical differentiation: An alternative way to obtain the instantaneous velocity is to make use of the *Lagrange's* formula for numerical differentiation for equally spaced abscissae. Suppose that you have the data consisting of five successive positions x_{-2}, x_{-1}, x_0, x_1 and x_2, where x_{-2} is measured at time t_{-2}, x_{-1} is measured at time t_{-1}, and so on. The derivative of x with respect to t at the central point, i.e. at time $t = t_0$ is given by

$$\frac{dx}{dt} = \frac{(1/3)}{\Delta t}\left[\frac{1}{4}x_{-2} - 2x_{-1} + 2x_1 - \frac{1}{4}x_2\right]$$

Where Δt is the time difference between two consecutive measurements. This expression is called Lagrange's formula.

Questions to Think About:

1. At a certain instant in time, an object which is freely falling towards earth has a speed of 15m/s. What is this object's downward speed exactly one second later (assuming the object does not hit the ground)?
2. The gas pedal on a car is often called the "accelerator". Why is this so? Is "accelerator" an accurate name? Hint, imagine pressing the pedal some amount and then holding it there as the car moves straight. Then, sketch position of the car versus time or velocity of the car versus time.

Equipment:

- An air table & its accessories.

The following items must be brought by you and will not be supplied:

- A 30 cm. ruler;
- Scientific calculator.

Procedure:

PART A: Motion with constant velocity

1. Level the air table using the three adjustable screws, so that the effect of the gravitation is minimum.
2. Make sure that there are no obstacles under the paper such as, accumulation of dust or eraser pieces left from previous user.
3. You will only use one of the pucks, so place the other one on one corner of the frame folding the paper to prevent it from being moved. However, both pucks have to be well over the carbon paper in order to produce dots on the ordinary paper by sparking.
4. Adjust the timer to the desired value. The spark timer has different sparking frequencies from which you may select before starting an experiment. You can also switch to a more appropriate frequency judging your data.
5. Using the switch pedal activate the vacuum pump and observe how the puck is moving. Make some trial pushes with the puck in order to feel confident with the setup.
6. Pressing two pedals together and giving a push to the puck, simulate a motion with constant velocity and generate a track for the measurement.
7. The spark positions are recorded as black prints on a paper laid on the air table, thus providing a permanent record of the successive positions of the two pucks at a succession of equally spaced time intervals. Ignore the first few data as they contain the initial acceleration due to the push. Start to measure the displacement (not the distance between two points!) and record the values in the Table 1. You must fill the entire table.
8. To find out exactly how fast the puck has moved we have to make Δt as small as possible. We thus proceed by choosing shorter and shorter time intervals. To do this, use the data pairs given and complete the Table 2.
9. Make a plot of the average velocity *v* as a function of the time interval Δt. Extrapolate your plot to $\Delta t = 0$. What is your estimate of the instantaneous velocity? Record your value in the desired location.
10. An alternative way to obtain the instantaneous velocity is to make use of the Lagrange's formula for numerical differentiation for equally spaced abscissae. Use the formula and calculate the instantaneous velocity around the data point 8 which is the middle point of the measured data range. Show your work and write down the result in the space provided.
11. Compare the values obtained from the graph and the Lagrange's formula.

PART B:

1. Place the wooden cube beneath the middle adjustment screw to give a proper inclination to the air table. The number on the cube indicates the sine of the angle of inclination.
2. Place one of the pucks at the highest point of the paper and activate the pedals. You will receive a pattern similar to shown in Figure 2 below. When the puck is released from rest, it accelerates downward with constant acceleration, provided air resistance is negligible. The

magnitude of this acceleration varies by a few tenths of a percent, depending on location, but it is approximately 9.80 m/s^2.

3. Start to take your measurements. Since this time we are interested in calculation of the Earth's gravitational field you must not ignore the first data points. Record the corresponding values in the Table 3.

4. Make a plot of x vs. t.

5. If x is plotted as a function not of t but of t^2, the result should be a straight line whose slope is $a/2$. Thus, make this plot and determine the acceleration of the puck.

6. Rather than to measure this acceleration directly, we measure the acceleration of the puck; from this we can compute g. If the angle of inclination of the air table is θ, the acceleration of the puck down the table is given by

$$a = g \sin\theta.$$

Thus, calculate and compare the gravitational constant with its theoretical value.

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Data & Results: [20]

Data Point	**Time t ( )**	**Displacement $x(t)$ ( )**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Table 1: Motion with constant velocity

Data Pairs	**Δt ( )**	**Δx ( )**	**v_{av} ( )**
1-15			
2-14			
3-13			
4-12			
5-11			
6-10			
7-9			

Table 2: Average velocity

Instantaneous velocity ( ) (from the graph)	Instantaneous velocity ( ) (Lagrange`s formula)	% Error

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$x(\quad)$	$t(\quad)$	$t^2(\quad)$

Table 3: Motion with constant acceleration

g (expected) ( )	g (calculated) ( )	% Error

Questions:

1) **[2.5]** Average velocity and instantaneous velocity are generally different quantities. Can they ever be equal for a specific type of motion? Can the instantaneous velocity of an object ever be greater in magnitude than the average velocity? Can it ever be less?

2) **[2.5]** Measurements on a moving particle show that its average velocity is equal to its instantaneous velocity at every instant. What can you say about its acceleration?

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3) **[2.5]** What are the possible sources of experimental errors in the experimental setup? Is it more appropriate to use a heavy (or light) puck, a small (or large) tilt angle in order to make a better estimate for *g*?

4) **[2.5]** Suppose you travel a distance *d.* If you travel at speed v_1 for half the total distance and at speed v_2 for the other half of the total distance, derive an expression for your average speed for the complete trip.

Conclusion: [10]

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Plot 1 [10]

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Plot 2 [10]

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Plot 3 [10]