Chapter 1

Uniformly Accelerated Linear Motion

Motion and changes in motion lie at the heart of physics. The genius of Galileo, Descartes and Newton in the 17th Century started us on our way. Their legacy has been refined and re-refined in the ensuing centuries.

Objective

1. To learn how to analyze experimental data and how to prepare the lab report.

2. To determine the acceleration of a glider on an air track.

Apparatus   Air track, computer, data acquisition system (Logger Pro), motion detector, digital level, graph paper.

1.1   Introduction

The experience of several centuries shows three quantities – displacement, velocity and acceleration (all functions of time) – are sufficient to describe the motion of an object.

The position in three dimensions is $\vec{x} = x\hat{i} + y\hat{j} + z\hat{k}$. The displacement is defined as the change in the position of the object: $\Delta\vec{x} = \vec{x_f} - \vec{x_i}$, where $\vec{x_f}$ is the final position and $\vec{x_i}$ is the initial position of the object. The velocity $\vec{v}$ is the rate at which the position changes. For infinitessimal changes in position we have:

$$\vec{v}(t) = \frac{d\vec{x}(t)}{dt}$$

The acceleration $\vec{a}$ is defined as the rate of change of velocity:

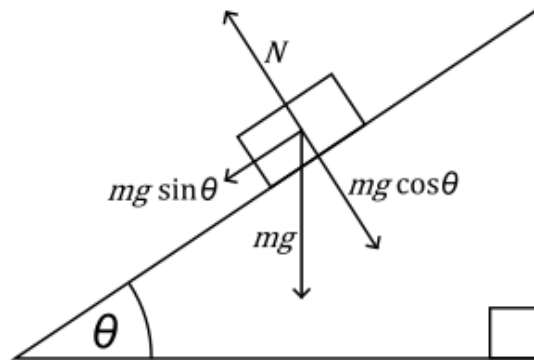$$\vec{a}(t) = \frac{d\vec{v}(t)}{dt} \tag{1.1}$$

Figure 1.1: Forces on an object on an inclined plane.

In this experiment you will consider a motion with constant acceleration. This is the motion when velocity increases or decreases at the same rate during the motion and it occurs whenever a constant net force acts. For this kind of motion $\vec{a}(t) = \vec{a}$ (i.e., the acceleration is not a function of time) and equation (1.1) becomes:

$$\frac{d\vec{v}(t)}{dt} = \vec{a}$$

which has the solution

$$\vec{v}(t) = \vec{v}_0 + \vec{a}t \tag{1.2}$$

where $\vec{v}_0$ is the velocity at $t = 0$. If the motion is only in one direction then this can be written $v(t) = v_0 + at$ where $v \equiv |\vec{v}|$, i.e., v is the magnitude of $\vec{v}$, and similarly $a \equiv |\vec{a}|$.

Since we want to examine uniformly accelerated motion we must control the design of the experimental procedure to ensure that we are indeed studying such motion. The basic requirement is a **constant net force**. As you read the instructions be conscious of how the procedure and the equipment fulfill this basic requirement.

In this experiment you will study the motion of a glider on an inclined air track. The air track permits a nearly constant net force from gravity because friction forces are so small they can be ignored. The glider, released from rest, starts to move with constant acceleration (shown in Fig.1.1 where g, the downward acceleration due to gravity, has the value 9.81 m/s^2).

Figure 1.1 shows the decomposition of weight into forces parallel and perpendicular to an inclined plane. Only the force $mg\sin\theta$ is responsible for the motion along the inclined plane. Thus, according to Newton's second law

$$
\begin{aligned}
ma &= mg\sin\theta \\
a &= g\sin\theta
\end{aligned}
$$

Experimentally the acceleration of the glider can be determined using equation (1.2). This represents a straight line with the slope equal to acceleration a, when the magnitude of the velocity v is plotted vs time t.

1.1.1 Prelab Exercise 1

Prelab exercises should be done before coming to the lab. Prelabs will be collected at the start of each lab.

The results of measurements of velocity, v of a particle versus time, t for constant acceleration motion, are given in the table below:

t (s)	0	3	8	16	21	26	30	35
v (m/s)	0	10	16	37	51	61	75	94

Uncertainties $\delta t = 0.2$ s and $\delta v = 2.0$ m/s are the same for all experimental points.

Draw the graph including error bars and determine the slope (which is the acceleration) using the method in section 0.3.5. Now, determine the acceleration and its uncertainty using the method of least squares described in section 0.3.6. (You may find it useful to use the table provided in the Useful Forms of Appendix D.) Do the two methods give consistent results?

Calculate the intercept and its uncertainty using the equations provided in section 0.3.6. What does the intercept represent? Is this fitted value consistent with that you expect?

1.1.2 Prelab Exercise 2

Determine the density, and its uncertainty, of a rectangular prism made of wood. Dimensions of the prism (length L, width W, height H) and mass M were measured. Results of the measurements are summarized below:

$$
\begin{aligned}
L &= (89 \pm 1) \text{ mm} \\
W &= (56 \pm 1) \text{ mm} \\
H &= (151 \pm 1) \text{ mm} \\
M &= (741 \pm 5) \text{ g}
\end{aligned}
$$

To determine the uncertainty of the density, follow the procedure explained in the lab manual in the section devoted to uncertainties.

1.2 Experimental Setup and Measurements

The setup is shown below. The computer is interfaced with a sound probe to measure the position of the glider, which is capable of nearly frictionless motion because it is supported

above the track by a thin cushion of air. The computer serves to collect, analyze and graphically display the experimental data.

A probe emits short pulses of sound which are reflected from the aluminum plate mounted on the glider. The reflected pulses are detected by the same probe that emits them. The electrical signal from the probe is amplified and digitized by the electronic unit and then transmitted to the computer. The time t that elapses between the emission and detection of pulses is measured precisely by the computer, and is used to compute the distance of the glider from the probe using the formula $x = vt/2$, where $v = 343$ m/s is the speed of sound in air. The data from the experiment is graphically displayed on the computer's screen while it is collected.
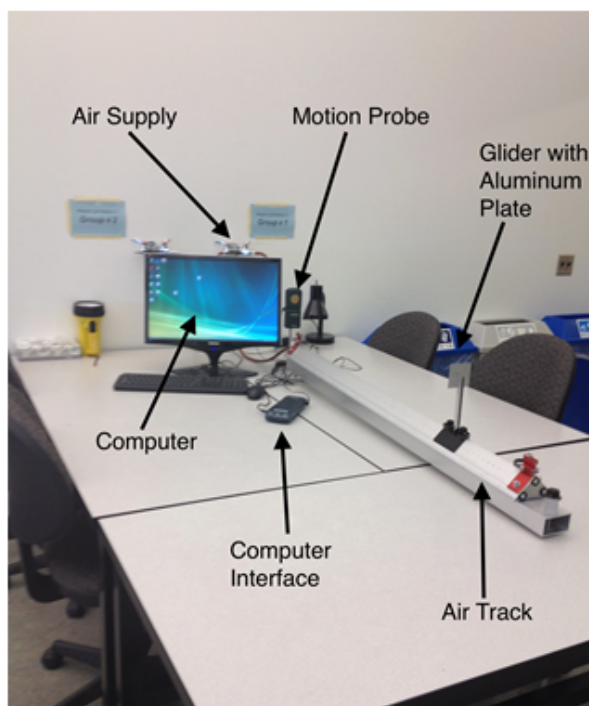

Figure 1.2: Experimental Setup.

The data acquisition system that controls the experiment is called Logger Pro.

Follow these steps.

1. To begin the experiment, double-click on the **Linear Motion** icon on the desktop.

2. Turn the air supply full on (both handles must be parallel to the air nozzles). Place the glider (fitted with a sound reflecting plate) at the top end of the inclined air track.

3. While holding the glider motionless, click **Experiment** on the menu bar and then click on **Zero** so that the sound probe sets the distance between it and the glider plate to zero.

4. When you are ready to begin the experiment, click on the button located in the menu bar and release the glider shortly <u>after</u> the button turns red so that the computer starts collecting data just before the glider starts moving.

5. Your experimental data will be plotted on the monitor in near real time. Once your data collection is completed, print two copies for you and your lab partner.

6. The data table should be in the form of columns of time, t and position, x. Close the file (click on **File**, select **Exit** and click on **No** so that the data is not saved in the document).

1.3   Calculations

1. Use your position x vs time t data to find the dependence of velocity $|\vec{v}|$ vs time t. The instantaneous velocity is equal to the slope of the graph of x vs t at a particular instant of time. It can be approximated by the average velocity $|\vec{v}| = \Delta x / \Delta t$, where $\Delta x = x_{i+1} - x_i$ is the change of the position in time $\Delta t = t_{i+1} - t_i$. You will fill out a table as shown below (sample values shown). Use the table provided in Appendix D to record your data and calculations for instantaneous velocity and median time as shown in the example table below. Cut or carefully tear it out of this manual and submit it as part of your lab report.

Time (s)	Position (m)	Velocity (slope) = $\dfrac{\text{Rise}}{\text{Run}} \left(\dfrac{\text{m}}{\text{s}} \right)$	Median Time (s)
0.0	0.000	$\dfrac{\text{Rise}}{\text{Run}} \dfrac{(x_{i+1} - x_i)}{(t_{i+1} - t_i)} = 0.075$	$\dfrac{0.0 + 0.2}{2} = 0.1$
0.2	0.015		
0.4			
0.6			

Figure 1.3: Sample table of data and calculations

Use adjacent experimental points when there is a significant curvature of the graph of x vs t. Use a larger part of the curve when it is nearly linear.

Assume that the absolute uncertainty for position is ± 1.0 mm and for time is ± 0.005 s. As $\Delta x = x_{i+1} - x_i$ (difference between two positions), then $\delta(\Delta x) = \delta x_{i+1} + \delta x_i$, where δx_{i+1} and δx_i are uncertainties of positions x_{i+1} and x_i, respectively. Thus,

$\delta(\Delta x) = \delta x_{i+1} + \delta x_i = 1.0 + 1.0 = 2.0$ mm.

The uncertainty $\delta(\Delta t) = \delta t_{i+1} + \delta t_i = 0.005 + 0.005 = 0.01$ s and is determined by the electronic unit controlling the Logger Pro acquisition system.

2. Plot the dependence of velocity vs median time. To find the uncertainty of velocity δv use the procedure described in section 0.2 **Measurement and Uncertainties** of the lab manual (steps shown below). Calculate the uncertainty δv for the first and last experimental points only and display these error bars in your graph.

$$
\begin{aligned}
v &= \frac{x}{t} \\
\frac{\delta v}{v} &= \frac{\delta(\Delta x)}{\Delta x} + \frac{\delta(\Delta t)}{\Delta t} \\
\delta v &= \left(\frac{\delta(\Delta x)}{\Delta x} + \frac{\delta(\Delta t)}{\Delta t} \right) v
\end{aligned}
$$

3. Calculate the slope of the straight line representing the dependence of velocity vs time using the method of least squares (section 0.3.6).

4. According to equation 1.2, the slope is equal to the acceleration. Use the procedure described in 0.3.6 of the manual to find the uncertainty δa of the acceleration.

5. Use the equation $a = g \sin \theta$ to determine the value of the gravitational acceleration g. Measure the angle θ using the digital level. Compare your result and see if it it consistent with the standard value. See section **Compare** in 0.2.2.

1.4 Questions

Answer all questions in your own words. Write legibly and be brief. Do not copy from your partner.

1. Is there any experimental evidence that indicates friction may have affected your results?

2. Using the expression $a = g \sin \theta$ and experimental value of acceleration a of the glider, Susan found the gravitational acceleration $g = (10.2 \pm 0.8)$ m/s^2. Is Susan's value consistent with the known value of g = 9.81 m/s^2?

END OF LAB

Was this lab useful, instructive, and did it work well? If not, send an email to thatlabsucked@gmail.com and tell us your issues. In the subject line, be sure to reference the your course, the experiment, and session. example subject: *PHYS1010 Linear Motion monday 2:30.* We won't promise a response, but we will promise to read and consider all feedback.