

Name: _____

Partner(s): _____

Date: _____

One Dimensional Motion

1. Purpose:

This lab has a dual purpose. We want you to become familiar with the operation of a linear air track and recognize this as another instance of the cultural preference that physicists have towards simplicity and minimalism. You will then use it to investigate the motion of a body subjected to a constant force and discover, experimentally, for this situation, the functional relationship between distance, velocity, and time.

2. Background:

➤ Required for this lab:

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| <ul style="list-style-type: none">a) Familiarize yourself with the basics of <i>Igor Pro</i> graphing softwareb) A good understanding of the lab reading material provided here.c) Science Workshop™ interface box (must be turned on)d) <i>DataStudio</i>™ software program (started <i>after</i> the Science Workshop™ box) |
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“Kinematics” is the study of motion, as opposed to “dynamics”, where one attempts to understand the “cause” of motion. In this experiment you will analyze one-dimensional motion and determine the equation of motion, expressed in the form:

$$x_1 = f(t) \tag{1}$$

where x_t is the location of the object at time t .

To study one-dimensional motion, you will use a cart and an air track. An air track is a *nearly* frictionless device, which can be used to study motion under ideal conditions. Carefully inspect all parts of the air track and note their function. It *is* a delicate instrument and should be treated as such. In particular, **don’t drop the carts!** If a cart is dropped, contact your instructor and ask them to inspect it carefully. With the blower on, inspect all the air holes to ensure that they are open.

In practice, we can never (or can we?) achieve a perfectly frictionless environment; even a levitated cart set in motion will eventually come to rest. Thus, you should investigate how good an approximation it is to consider the air track frictionless.

The **simplest example** of motion is an object moving at constant velocity, v_o , in a straight line. In this case, the change in an object's position after a period of time, Δt , is trivial:

$$\Delta x = v_o \Delta t \quad (2)$$

When the object is accelerating (*i.e.* the air track is inclined, or there is substantial friction, or there is a big draft of air, *etc.*) this relationship will be more complex.

The **next-simplest case** is if the acceleration a is uniform (*i.e.* does not vary over the time of the experiment); then the change in an objects position is:

$$\Delta x = v_o \Delta t + \frac{1}{2} a (\Delta t)^2 \quad (3)$$

where v_o is the initial velocity of the object at the beginning of the interval Δt and a is the uniform acceleration that the object is subject to. Because the acceleration is constant, the velocity, v_f , of the object after time, Δt , satisfies:

$$v_f = v_o + a \Delta t \quad (4)$$

$$v_f^2 = v_o^2 + 2a \Delta x \quad (5)$$

You can derive Equation (5) by squaring Equation (4) and substituting in Equation (2).

If the acceleration, a , is itself changing with time, the equations of motion are more complex. For now, you will study the motion of the cart down the inclined air-track for which equations (3) and (5) will *probably* provide a reasonably good description.

3. Procedure:

The setup is depicted in Figure 1. Data will be taken using two photogates, shown in the figure as G_0 and G_1 . The air track will be elevated at one end, and you must determine the resultant angle of inclination.

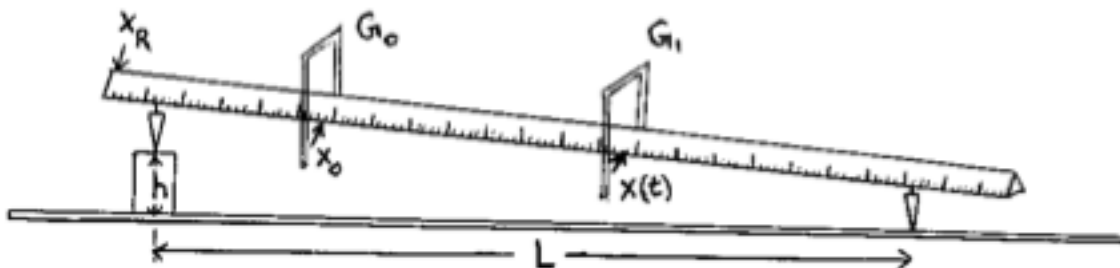


Figure 1

In the first part of this lab, you will measure the duration of time, t , that it takes for the air cart to travel a distance $\Delta x = x(t) - x_o$ on the air track. The distance Δx is the distance that the cart travels between the two photogates. You will repeat this six times for six different distances, Δx .

If the velocity at the initial photogate, v_o , and the acceleration remain the same during each run, then you should have the form of Equation (3). The acceleration will be constant if the angle of inclination, θ , remains constant and any frictional forces do not depend on the location or speed of the cart. Additionally, if you start the cart from rest *at the same point* on the air track and the position of the first photogate remains *fixed* during each measurement, the velocity at the initial photogate will remain constant. Different distances Δx can then be obtained by varying (only) the location of the *second* photogate.

Before you can make your first computerized measurement, ensure that your photogates are connected to a Science Workshop™ interface box, and that the box is turned on. After that, you can initialize the DataStudio™ control software and select “Create Experiment.” This brings up a graphical representation of the interface box, showing its various front-panel connectors.

- Click on the picture of the connectors your photogates are connected to, and use the resulting dialog box to let the control software know that that you do indeed have **photogates** connected. Do this for each of the two inputs that you are using.
- Now that you have configured the inputs, select any measurements you would like the control software to retain.
- Click on the "third tab" generated and enter the width of the paper "flag" attached to your cart that will actually *trigger* the photogates.
- You also need to enter the separation between photogates. (You will want to *update* this entry whenever you change the set-up.)

By inspection, you might expect that the acceleration, a , depends upon the angle of inclination, θ , of the air track.

- In the space below and on the next page, draw a force-body diagram of the cart and apply Newton's 2nd Law to find the acceleration of the cart in the direction of motion.

You should find that the acceleration is given by Equation (6).

$$a = g \sin \theta \quad (6)$$

- Keeping θ fixed is easy: place a block of fixed height h under one end of the air-track. (Some air-tracks only have bumpers at one end; make sure that the lower end of your air track does have one!) The first photogate must be kept stationary, perhaps 15-20 cm from the high end of the track.
- You should measure seven “reasonably spaced” data points covering the entire length of the air track.
- For each distance Δx in Table 1, find the time interval Δt by averaging over six trials.

4. Data:

Determine the angle of inclination:

$$m_{\text{cart}} = \underline{\hspace{2cm}}$$

$$h = \underline{\hspace{2cm}}$$

$$L = \underline{\hspace{2cm}}$$

$$\theta = \tan^{-1}(h/L) = \underline{\hspace{2cm}}$$

- Consult the drawing on the previous page to make sure that you measure the proper h and L . The most common error made is an incorrect determination of the angle of inclination!

Measuring the Time of Travel for Various Distances:

Be sure you are recording, here, the time *between* Gates 1 & 2, and not some *other* time!!

Trial	x_0 (Initial Gate)	x_f (Final Gate)	Δt (Time)	Δx (Displacement)

5. Analysis:

Part 1:

- Enter your data, Δx and Δt , into your graphing program, *IGOR Pro*. From the previous discussion, we know that the relationship should be modeled by Equation (3), but graphing programs tend to supply more generic looking fitting functions, so we often have to re-phrase the equations associated with our physical models so as to match up with the syntax of the graphing software: here, we expect that your plot of Δx and t should appear to **resemble** a *polynomial of second order*, as seen in Equation (7).

$$y(x) = a_0 + a_1x + a_2x^2 \quad (7)$$

Here, y and x refer to the y -axis and the x -axis of a graph, not physical quantities, and a_0 , a_1 , a_2 represent the adjustable coefficients of the polynomial. They are adjusted by your curve-fitting software in order to make the fitting curve *best* approximate your data. It is then up to you to decide whether the resulting polynomial is a physically reasonable (or “meaningful”) fit to your experimental data:

- Perform the fit and record the “best-fit values” output by your graphing software for the polynomial coefficients:

$$a_0 = \underline{\hspace{2cm}}$$

$$a_1 = \underline{\hspace{2cm}}$$

$$a_2 = \underline{\hspace{2cm}}$$

- Attach a copy of your graphed data, including the fitted line.

Again, once your graphing software “spits out” a fit to your data, it is then up to you to decide whether the resulting polynomial is physically reasonable (or “meaningful”): comparison of equations (3) and (7) tell us that, according to our physical model, we expect a_0 to be 0, a_1 would correspond to v_o and a_2 would be $g \sin \theta / 2$. You have already computed a *theoretical* value for \mathbf{a} using Equation (6). You should also compute a theoretical value of v_o , by using Equation (3). With these in hand, complete the table below:

	Experimental	Theoretical	% Error
acceleration, a ()			
initial velocity, v_o ()			

❖ Does your *fitted* value of a_0 agree with what you expect? Comment.

❖ Does your *fitted* value of a_1 agree with what you expect? Comment.

❖ Does your *fitted* value of a_2 agree with what you expect? Comment.

Part II:

We can also study kinematics by measuring the initial velocity, v_o , and final velocity, v_f . When you measured the time that the cart spent between the photogates, the software also measured the time required for the cart to pass through **each** photogate, Δt_0 and Δt_f . If the length, ΔL , of the flag that passed through the photogate is sufficiently small, the quantities $\Delta L/\Delta t_0$ and $\Delta L/\Delta t_f$ provide good approximation to the instantaneous velocity of the cart as it passes through each photogate.

The choice of the length, ΔL , is a *compromise* between two conflicting needs. If ΔL is too small, then the transit time is too small to measure precisely and the percentage error in determining $v(t)$ becomes unacceptably large. On the other hand, if ΔL is too large, the measured speed is not a good approximation to the instantaneous speed. Be careful in determining your value of ΔL .

Explain your method in the space below.

If you were careful to include the necessary measurements when taking your data earlier, you do not need to make any additional measurements now. (Aside: reading the lab write-up ahead of time does save you time in lab!) The table below will guide you through what is needed to **calculate the acceleration using Equation 4**.

$$\Delta L = \underline{\hspace{2cm}}$$

Δx (Displacement)	Δt_0 (Time, Gate 1)	Δt_f (Time, Gate 2)	v_0 (Velocity, Gate 1)	v_f (Velocity, Gate 2)	a_{cal} (Accel)

$$a_{average} = \underline{\hspace{2cm}}$$

7. Initiative:

Possible ideas:

- Design an experiment to determine the *extent* of frictional effects on the air track. Do this experiment and present your data and analysis.

8. Conclusions: