Motion on an Inclined Plane

Goals of this lab
- observe motion on an inclined plane
- observe the effects of friction and understand where it comes from
- determine the acceleration of gravity
- see the relationship between position, velocity, and acceleration
- find the force of friction on the air track

If frictional forces could be made to disappear a block placed on an inclined plane would slide down the plane no matter how small the angle of inclination. When the angle is small the object will move comparatively slowly down the incline due to gravity. This was Galileo's basic method for finding the acceleration due to gravity --- the first real measurement of it.

We can make friction nearly disappear with the air-track. **Figure 1** shows a "glider" on an air track. The glider floats on a cushion of air emerging from many tiny holes in the track. The rectangular "flag" is needed for measuring the position with a motion detector. The single leg of the air-track shown in the figure is elevated above the lab bench with spacers placed under it to incline the air-track at a small angle.
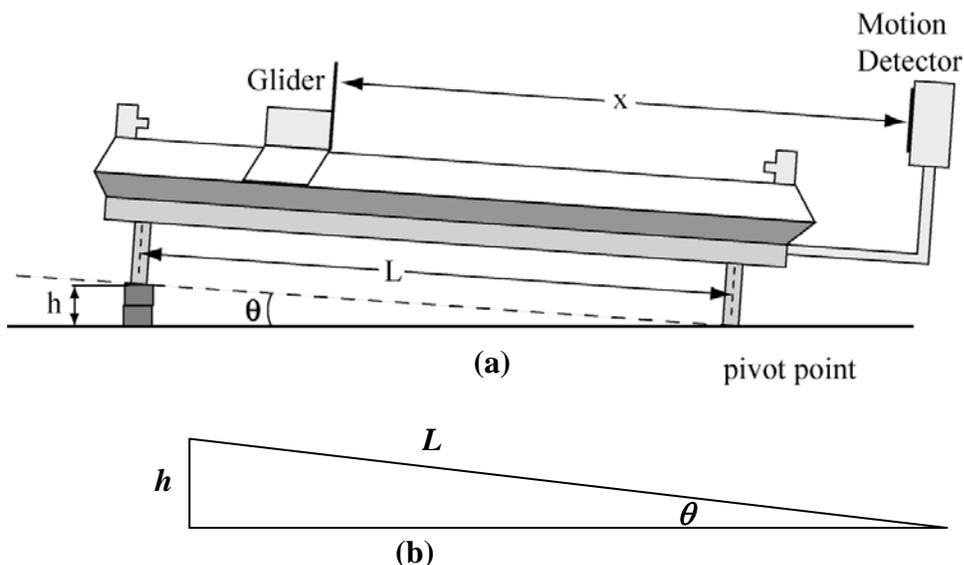

Figure 1:The glider on the airtrack

In this experiment we will determine *g*, the acceleration of a freely falling object near the earth's surface, by measuring the acceleration of the glider moving on an inclined track. The glider's acceleration (ignoring friction) is given by

$$a = -g\sin\theta \quad (1)$$

where θ is the angle of the inclined plane and the negative direction is towards the motion detector which is also down the ramp.

Figure 2 below is a drawing of the air-track, glider and motion detector in Figure 1. The distance **x** between the glider and the motion detector is the measured position of the glider.

(a)

(b)

Figure 2

(a) Top: Glider on the inclined air-track- showing the inclination angle.

(b) Bottom: The similar triangle used to find the inclination angle of the air-track.

One end of the air-track has a support with two legs and the other has a support with one leg. The inclination angle, θ, is set by inserting small spacer(s) of height h under the one leg support. The air-track will be inclined as shown in **Figure 2(a)**. The sine of the angle θ is found from the sides of the triangle shown in **Figure 2(b)**. The distance L between the two supports at the opposite ends of the track is fixed at 1 meter.

Not shown in the figure is a large piece of black fabric over the upright rods at the end of the airtrack. The purpose of the black fabric is to avoid problems with the motion detector when the glider is near the far end of the air track.
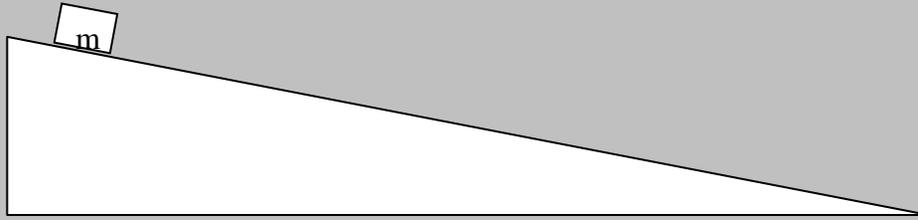
PreLab Question 1

1) Measure the sides of the triangle with an ordinary ruler and calculate $\sin \theta$.

2) Find the uncertainty in $\sin \theta$.

$$\sin \theta = \frac{a}{c}$$
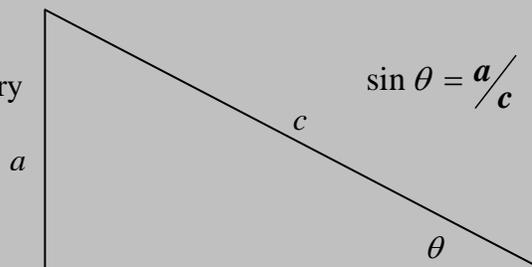
Prelab Figure 1

PreLab Question 2
Draw a free-body diagram of the mass on the incline as shown below.

Prelab Figure 2

What does friction do to the motion of the glider on the inclined track? Friction is always directed opposite to the *velocity* of the moving object and hence points downward during the upward trip and upward during downward trip. There is a small but measurable difference between the accelerations when the glider moves up the air-track and down the air-track due to the effect of friction.

Applying Newton's second law to the motion gives

$$ma_{down} = -mg \sin \theta + f \qquad \text{(2a) going down the inclined track}$$
$$ma_{up} = -mg \sin \theta - f \qquad \text{(2b) going up the inclined track}$$

Equations (2a) and (2b) can be added together, in which case the friction terms will cancel out. Dividing this equation through by 2*m* will reduce this equation to equation (1), with *a* being the average of the up and down accelerations.

> **Prelab Question 3** Indicate on a sketch of the Figure 3 Velocity-Time graph where the glider reaches the highest point on the air-track, where it is going up the track and down the track and where it contacts the bumper.

The motion graphs in **Figure 3** were created with the glider moving on an inclined airtrack. If the glider is released it will accelerate down the track, strike the bumper at the bottom, rebound and move upward, come to a momentary stop, and then repeat the motion over again. Due to friction and bumper losses, the motion stops after several cycles.

The minima in the Distance-Time graph correspond to rebounds from the bumper and the maxima of the rounded parts

correspond to the glider at its highest point on the track.
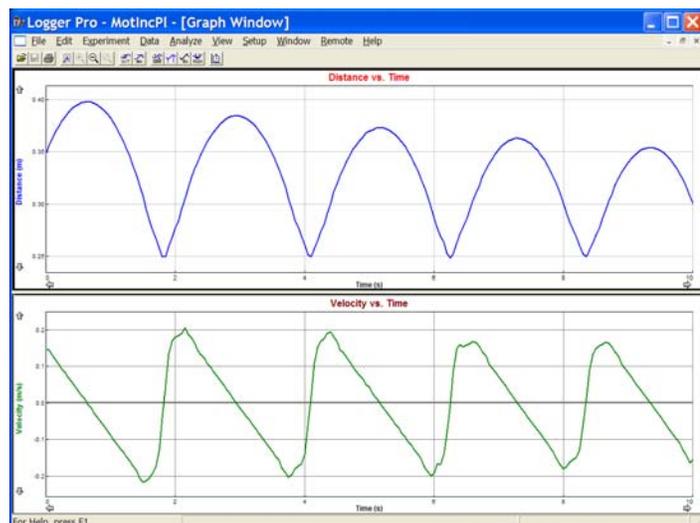
Figure 3: Motion Graphs of the glider on an inclined track.
Top graph: Distance-Time ; Bottom graph: Velocity-Time

The "free-motion" parts of the Velocity-Time graph, when the glider is not contacting the bumper, are line segments. Positive velocity means the glider is moving away from the ranger (up the track). Wiggles in the graph are from experimental noise.

The motion graph in **Figure 4** was created with the glider moving back and forth on a <u>level</u> air-track. The free motion segments of the graph, i.e. the segments between collisions with the bumpers, are ***almost*** horizontal. They would be horizontal if the track were perfectly level and if the glider were perfectly balanced.

Free-motion
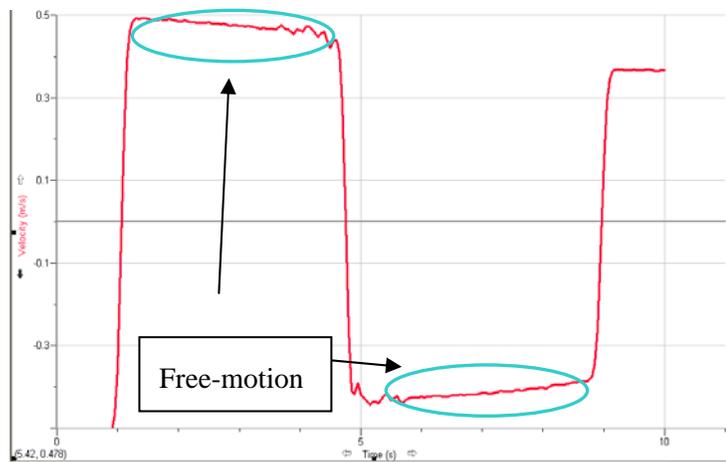
Figure 4:Velocity –Time graph of the glider moving on a level air-track

Procedure

1) MacMotion should be set-up so you can see position-time, velocity-time, and acceleration-time windows. Place the glider on the track with all attachments. Make sure the black fabric screen is in place on the rods

2) To level the track, see if the glider drifts consistently in one direction and adjust the single leg as necessary. Use one of the motion graphs to check this adjustment.

3) There are several small blocks on your table. Measure the thickness of one of these blocks using dial calipers, then place it under the single leg. Calculate the resulting angle of inclination.

4) Let the glider bounce against the lower bumper several times. Set the data collection time so you can fit 4-5 bounces on the motion graph if necessary. You will average data from all the bounces.
   - Measure the acceleration experienced by the glider with uncertainty:
     o while it is moving upwards on the track.
     o while it is moving downwards on the track
   - Average the two accelerations with uncertainty.
   - Measure the average acceleration of the glider for a few round-trips up and down the air-track. Compare this value and its uncertainty with the average of the two averages

5) Repeat step 4 for at least four different inclinations of the air-track using the method you think is best. Graph the acceleration vs. $\sin\theta$ for the different inclination angles using Graphical Analysis.   Submit this graph with your data at the end of lab.
(Note: When using multiple spacers, it is better to measure the thickness of all spacers together.)

6) Use equations 2a and 2b to calculate the force of friction. (Bonus: Do this for more angles.)

7) Determine what the source of friction is and what it depends on. Support your conclusions.

Questions

1. Which graph did your group use in step 2 to level the air track? Why?
2. If the friction force were not constant, how would this affect the calculation of the average acceleration of the glider using equations (2a) and (2b)?
3. What is the largest source of error in this experiment?
4. Why is the acceleration-time graph a poor way to find the acceleration?
5. What affect does the balancing of the cart have?

Your Lab Report must include:

- Uncertainties for ALL measurements.
- A calculation of the accelerations attributable to gravity and those attributable to friction.
- The graph of acceleration vs $\sin\theta$ and its regression line including error bars.
- An estimate of gravity using this graph's regression line.