Experimenting with a linear air track

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May 27, 2019
Version 2019-v1

An air track is a perforated rail which is connected to an air blower. Compressed air is sprayed from the holes and forms a thin layer on the surface of the track. This layer fills the space between the air track and the inner surface of a glider. As a result, the movement of the glider can be regarded as almost friction-free. This apparatus can be used to experimentally study important concepts in kinematics such as velocity, acceleration, momentum, collisions, and kinetic energy. It is an ideal teaching aid for physics. In this experiment, we provide students with an opportunity to explore some of these ideas through experiments that they can devise on their own.

KEYWORDS

Speed; acceleration; momentum; kinetic energy; friction; acceleration due to gravity; free body diagram; photogate

1 Objectives

In this experiment, we will,

1. understand concepts of instantaneous and average speeds and measure them using a photogate;

2. measure acceleration;

3. find momentum and its possible conservation during collisions;

4. learn how to use graphical data to infer physical quantities and commenting on their uncertainties;

5. learn about a free body diagram and observe Newton's force law in action;

6. measure effects of friction and energy losses.

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Your instructor will guide you on which experimental configurations you will be required to investigate. We largely expect students to come up with their own experimental strategy to investigate various phenomena. Now let's get you started.

2 The Experiment

The experimental setup comprising the air track connected with an air blower and a pulley affixed on its edge is shown in Figure 1. The glider is a V-shaped metal frame that glides on the air cushion. Each glider has two flags attached on its edges. Their motion is detected with the help of photogates which are connected with the computer through Physlogger, which is our data logging device. During its motion, when glider passes through the inverted U shaped arms of the photogate, the Physlogger channel detects two rectangular pulses, one when the flag at the entering edge of the glider passes through the photogate and second when the flag at the leaving edge passes through the photogate.
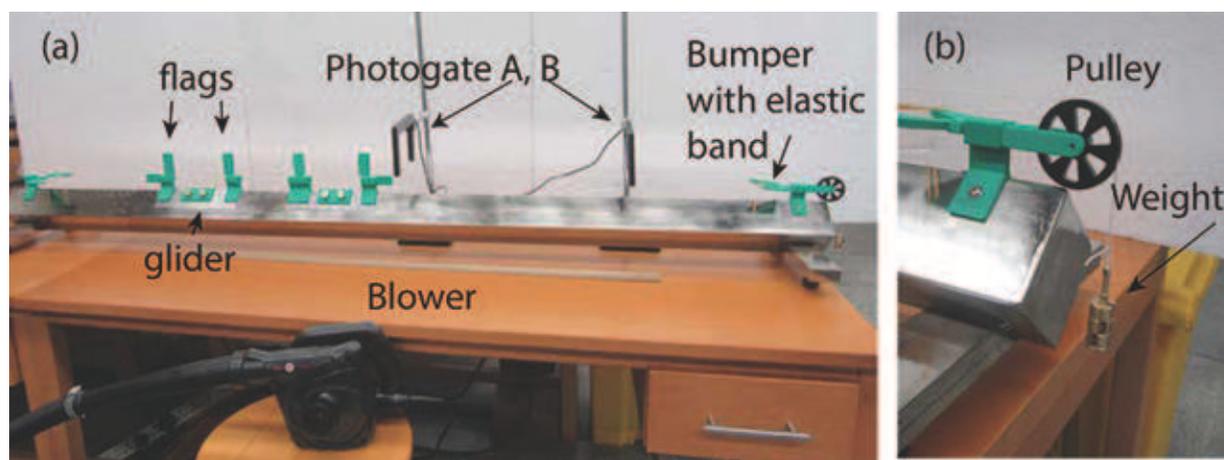

Figure 1: A photograph showing the (a) air track with all its accessories and (b) a close-up of the end pulley which allows a weight to be hung from a thread.

3 Preparing for the experiment

Before starting the experiment, make sure to verify the following aspects.

1. The air blower is turned on. **Turn on the air blower only when required. Do not keep the blower on for more than ten minutes. This will prevent over heating and damage to the blower. The experiments are brief and should be briskly conducted. The blower should be turned off during the data analysis stage.**

2. The air track level is adjusted with the help of leveling screws at the bottom of the track. When the track is balanced, a glider will not appreciably move in either direction.

3. Photogate A is connected to channel 1 and Photogate B is connected to channel 2 of Physlogger. The wires labeled `Photo` are connected to the terminals labeled `A+` and `B+` while `G` is connected to the identically named terminal on Physlogger.

4. **Notes about configuring Physlogger:**

   (a) Ensure that Physlogger is connected to the PC using the USB cable.

   (b) The channel types are each set to `Analog In RSE` mode, and

   (c) the individual input ranges are set to ± 6 V.

When connected, if the Physlogger app is showing the photogate signal on it's channels and responding to obstacles detected by the photogates, it means that the apparatus is ready to use. Your instructor will provide you more details about using Physlogger. Alternatively, you can download the user manual from this website [1].

4 A basic exercise

Let's do a basic exercise of detecting a signal when the glider passes through the photogates,

1. Place photogate A 45 cm away from the left edge of air track and photogate B 100 cm away from photogate A.

2. Connect photogate A to channel 1 of Physlogger and photogate B to channel 2 of Physlogger.

3. Starting from the extreme left, slightly push the glider by hand and let it cruise to the right end. First this glider will intercept photogate A and at some later time photogate B.

4. For example, Physlogger's channel 1 will show two rectangular pulse signals when the glider intercepts Photogate A (see Figure 2). Likewise, two pulses will be detected for photogate B and displayed on Channel 2. The two pulses correspond to the flags on the glider. You are provided with measuring rules to measure the lengths and mutual distances between these flags.

Now let's do some interesting exercises on this apparatus.

5 Idea Experiments

1. **Measure speeds and finding their uncertainties:** Using a single slider move across the air track, measure the speeds of the (a) flags, and the (b) glider on the locations of the two photogates placed ≈ 100 cm apart. In this experiment, you can find the speed of a flag by measuring, say, $t_2 - t_1$ and the speed of a glider by measuring $t_3 - t_1$ or $t_4 - t_2$. Other schemes are also possible. In which of these quantities do you see the
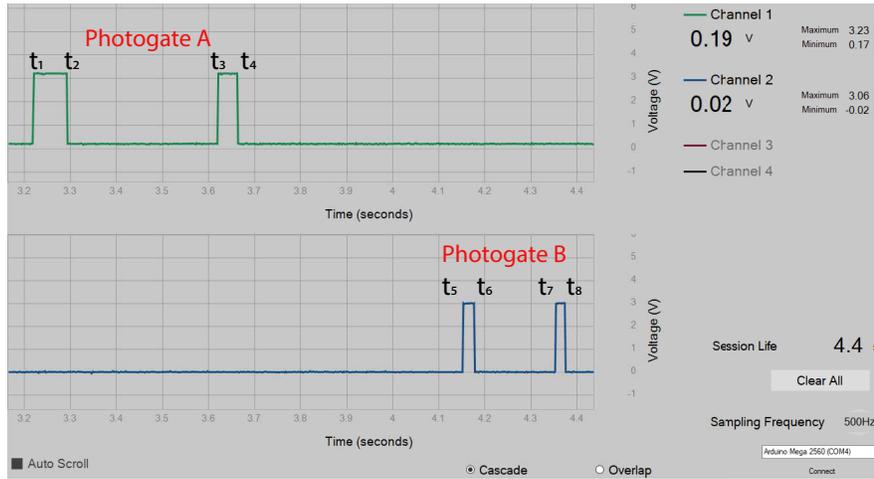
Figure 2: The waveforms acquired on Physlogger when a single glider passes through the photogates A and B spaced 100 cm apart. The markers t_1 through t_8 are also marked.

    largest variation? Comment on the uncertainties of the speeds. What's a more precise estimate of the speed of the glider? Are these speeds measures of *instantaneous* or *average* speeds?

2. **Average speeds:** Find the average speed of a glider between locations A and B. There are different time intervals you could use for determining the average speed. Recognize these various methods and estimate the average speed. Discuss with your instructor.

3. **Energy and momentum losses:** How does the momentum and the energy of the slider decay as it makes multiple round trips on the air track? Connect the rubber bands on the end bumpers on both ends for this part of the experiment. Could you plot these energy and momentum losses and explain the origin of these losses? How do the speeds and momentums change when two gliders collide with one another. Is the collision elastic?

4. **Acceleration and free body diagram:** Measure the mass m of the glider with the provided weigh balance. Tie a thread to the neck of a flag that is attached to the glider on the end closest to the end-pulley. Attach a weight M to the weight hanger and hang it to the end of the thread which passes over the pulley. Adjust the length of the thread and the location of the photogates such that that when the weight M is at its highest location, the glider finds the opportunity to intersect both the photogates in the weight's downward descent. Measure the average acceleration a of the glider. Repeat the experiment a few times with the same mass M. Subsequently, repeat for different masses M.

    Draw a free body diagram for the hanging weight and the glider, showing the tension in the string and the acceleration of the objects. Derive a formula showing the relationship between m, M and a. Does your experimental data verify this relationship? Draw a graph to elaborate your findings. Can you modify your formula to elicit a linear relationship? Finally, estimate the value of the acceleration due to gravity g deduced from your data.

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5. **Automating calculation of the acceleration** Could you write a computer program that takes the data saved from the Physlogger's session and computes the acceleration? Well, if you can try this on your own, then bravo! If you don't want to try, you could also draw from a collection of Matlab scripts from our website that automatically computes the acceleration for you. Put all of these files *and* your data files recorded from Physlogger into the same folder. Suppose your filename with the recorded data is `example.txt`. Typing the following command in Matlab's command window will compute the acceleration in cm s^{-2} for the dimensions and sizes of the provided air track accessories.

```
AirTrackAcc('example,txt')
```

References

[1] Details on the Physlogger and the user manual can be read from here: `https://www.physlab.org/facility/physlogger/`.