Newton’s 2nd Law
(Includes Pre-Lab Assignment)

Objectives

These lab activities will focus on relationships between force and acceleration. The lab will consist of two separate sets of measurements: 1) Varying $m$ while keeping $\vec{F}$ constant and measuring $\vec{a}$ and 2) Measuring $\vec{a}$ for an object on an inclined plane with varying $m$.

For the following activities, you will use a physics simulation program. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links.

Introduction

$\vec{F} = m\vec{a}$ can be tested by applying a known force ($\vec{F} = m\vec{g}$ from gravity) and measuring the acceleration of the track’s cart. In this experiment there are two masses: $m$, the mass of a cart, and $m_h$, a hanging mass. The two masses are attached, so both are accelerated at the same rate, so the total mass that contributes to the acceleration is $(m + m_h)$.

In the first set of measurements you will use a fixed hanging mass ($m_h$), and hence a fixed force ($F = m_hg$). Mass will be added to the cart, so that:

\[ F = m_hg = (m + m_h)a \quad \text{or} \quad a = \frac{m_hg}{m + m_h} \quad (\text{Eq. 1}) \]

where $m_h$ is constant. Here $F$ is constant because the only accelerating force is gravity pulling the hanging mass down. Hence $a$ increases when the total mass $(m + m_h)$ decreases – they are inversely proportional.

In the second set of measurements, you will use a near frictionless inclined plane. The component of the net force acting parallel to the surface of the plane will be:
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\[ F_\parallel = mg \sin \theta = ma \quad \text{or} \quad a = g \sin \theta \quad \text{(Eq. 2)} \]

This relation (Eq. 2) is independent of the mass of the cart! You will measure \( \ddot{a} \), compare it to \( g \sin \theta \), and verify that acceleration is independent of cart mass.

**Simulated Apparatus:**

You will make your measurements on a frictionless Track which eliminates influence of the external environment. The basic setup consists of the track with rubber bumpers at each end, one cart, one pulley, and two photogate timers.

Four 50 g weights will be added to the cart to measure \( \ddot{a} \) vs. \( m \) for fixed \( \vec{F} \). A 50 g hanger will provide the force. A string attached to the cart post goes over the pulley and attaches to the hanger. Additional weight may be added to the hanger to increase the force. A scale will be used for mass measurement.

**Measuring Acceleration**

You will measure acceleration, \( a \), by measuring a change in velocity over time. The lab computer will measure the time that it takes for a cart to pass through two sequential photogates, \( t_1 \) and \( t_3 \), and the time interval between the gates, \( t_2 \). These three times are shown schematically below.
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The speed of the cart in the first gate \(v_1\) and the second gate \(v_2\) are given by:

\[
|v_1| = \frac{L}{t_1} \quad |v_2| = \frac{L}{t_3}
\]

where \(L\) is the length of the cart. The acceleration is the rate of change of velocity with time, so we must be careful – the velocities \(\hat{v}_1\) and \(\hat{v}_2\) are not instantaneous velocities, but instead are average velocities. To minimize the effects of a finite interval on the velocity measurement, we will take the time difference between the velocity measurements as:

\[
\Delta t = t_2 - \frac{1}{2} t_1 + \frac{1}{2} t_3
\]

and calculate \(\hat{a}\) as:

\[
\hat{a} = \frac{\hat{v}_2 - \hat{v}_1}{\Delta t}
\]

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**Part I: Acceleration by a Hanging Mass**

1. Setting Up the Apparatus

1.1: Measure and record the length of the cart using the ruler. Note any uncertainty in the measurements. Record the mass in kg of the cart at 250 g and weight hanger at 50 g; the string is considered massless.

1.2: Set up the photogates and pulley.

- With the brakes on, grab and drag the spool of string to the end of the cart. It will fix itself in place. Loop the other end around the pulley. Now hang the mass hanger from it.

- Click on the ruler symbol to toggle the onscreen measurement.

- Pull the cart back and center it at 9.0 cm. Turn on the photogates and reduce the number of them to 1.
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- You can move photogates by dragging them by their flags. Place this photogate at 40 cm on the ruler. This is your left-hand photogate, referred to as photogate #1.

- Increase the number of photogates to 2. Set photogate #2 at 80 cm on the ruler.

**NOTE:** The order of the photogates matters. Ensure that the photogate on the left is the first gate the simulation generates.

1.3: Set the “Card Width” to 35 cm.

1.4: Open the Excel spreadsheet template provided with this week’s lab.

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### 2. Newton’s 2\textsuperscript{nd} Law on a Level Track

You will first take several measurements to estimate uncertainties that may be affecting the precision or accuracy of your measurements. Since the sensors in the simulations are perfect, we introduce uncertainties through the procedure, so please follow it exactly. You will then measure $\ddot{a}$ while varying $m$ and holding $\vec{F}$ constant. Be sure to draw force diagrams in your notebook describing the force acting on the cart for each configuration.

2.1: Release the cart by turning off the brakes—stop the cart by turning the brakes back on. Do so before it hits the bumper and recoils back through the photogates. Try this a couple times before we take data.

2.2: Ensure the cart is centered at 9.0 cm. Record this position in your notebook.

2.3: You will take your data with the following procedure:
   - a. Click **Take Gate Data**
   - b. Turn off the brakes and let the cart pass through both gates.
   - c. Click **Stop Gate Data**
   - d. Record the data displayed on the gates in your spreadsheet.
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\begin{enumerate}
\item Turn the brakes on, move the cart back to 9.0 cm and click \textbf{Clear Gate Data}
\end{enumerate}

2.4: Open the Excel template provided with the simulation. You will input data from the photogate flag. The figure above shows two data points; \(eT\), the time the sensor detected the cart and \(dT\), the time that the cart was visible to the sensor. Input these into your spreadsheet in the line \textbf{Run 1} in the first tab, \textbf{Raw Data Level Track}.

2.5: Repeat steps 2.1 – 2.4 three more times and input the data into the spreadsheet in the rows \textbf{Run 2} through \textbf{Run 4}.

Make sure to record the value for total mass \((m+m_h)\) in the final column, where \(m_h\) is mass of hanger and \(m\) is the total mass of the cart, use standard units.

\textit{NOTE:} In your spreadsheet notice rows labeled \(\Delta t\), \(a\), mean, std dev, and \(\delta a\) these will be automatically calculated for you. The “Std. Dev.” (standard deviation) is a statistical calculation of the spread of your data. It is a useful function because it allows computers to calculate random uncertainties. Recall in the “Acceleration Due to Gravity” lab that you estimated something like this from the spread of your measured values.

2.6: Repeat steps 2.1-2.5 for the four cases below. Return to the “Raw Data Level Track” tab to take measurements. \textbf{The masses must be added onto the cart – not the hanger – for your model in Eq. 1 to properly fit your data}. Make sure to release the cart from the same position for every measurement.

\begin{enumerate}
\item One 50-gram weight on the cart
\item Two 50-gram weights on the cart
\item Three 50-gram weights on the cart
\item Four 50-gram weights on the cart
\end{enumerate}

2.7: Now that you have five values of acceleration for different cart masses, It is time to plot your data. Copy the calculated averages from the rows titled mean into the rows of the \textbf{Level Track Measurements} tab, and calculate the value of 1 divided by the total mass in the column \textbf{1/Total Mass}. Excel
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should automatically plot your data with 1/Total mass on the x-axis and acceleration on the y-axis. Using your data we will compare to the model for the expression in Eq. 1 from above.

2.7.1: Determine the mathematical model you will use to represent the physical hypothesis stated by Eq. 1. Explain why you chose that model and what terms in Eq. 1 the parameters refer to.

2.7.2: Add a trend line to fit your data, and make sure to choose Display Equation on Chart, to see your fit parameters. Depending on your model, you may also want to force your y-intercept to be a specific value.

2.7.3: Take a screenshot of the page and include it with your report.

2.8 Questions:

- Describe (and show with pictures) what forces change for each of the different configurations you used in this section.
- You should be able to calculate a value for \( g \) from the fit parameter used in 2.7. Do so now. How accurate is your calculated value? Discuss any uncertainties that you think may have contributed to your value differing from 9.8 m/s\(^2\).
- Newton’s 2\textsuperscript{nd} Law stipulates that the sum of the forces acting on an object is equal to the mass times the acceleration of that object. Is that what you observe? Why does/doesn’t your data agree with this statement of the second law? Are there forces acting on the cart that you are not accounting for?
- \textit{Thought Experiment:} What is the difference between normal force and weight? Give an example where the normal force and the weight of an object are the same. Give two examples where they are not the same.
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Part II: Newton’s 2nd Law on an Inclined Plane
3. Measuring $\ddot{a}$ on an Inclined Plane

In this experiment, you are testing the theoretical hypothesis that an object moving down an inclined plane solely under the influence of gravity accelerates independently of the mass of that object (Eq. 2). Draw force diagrams in your notebook describing the force acting on the cart for each configuration.

3.1: Prepare the inclined plane. In this part you will not use the hanger, string, or pulley. Click the “Reset All” button to remove them. Tilt the table by about 1°. Because of the angle of the inclined plane, the cart should be accelerated by the force of gravity toward the other end of the track.

3.2: Repeat steps 2.1-2.7 for the cart accelerated by the incline with varying mass added to the cart. But be sure to use the Raw Data Inclined Track and Inclined Track Measurements instead. And, instead of using a model based on equation 1, what model will you need?

3.3 Questions:

- Does acceleration depend on the cart mass? How do you know?
- Calculate $g$ using Eq. 2 from above. How accurate is your calculated value? Discuss any uncertainties that you think may have contributed to your value differing from 9.8 m/s$^2$.
- From your force diagram of the cart on the inclined plane, describe (analytically and mathematically) the relation between the normal force and the weight of the cart.
- Thought Experiment: Here the track is frictionless, but in reality, this is not usually true. How would our Newton’s 2nd Law models (Eq. 1 and Eq. 2) of the two systems studied in this lab change if we were to account for the force of friction acting on the cart as it travels across the track? Draw force diagrams to help you. Use $F_f$ to denote the mathematical term for the force of friction.
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Pre-Lab Assignment (1 point)

1. Newton’s 2nd Law stipulates that “the sum of all forces acting on an object are equal to the mass times the acceleration of that object.” Given the force diagram below, calculate the acceleration of the object (both magnitude and direction). The object is the smiley face, which has a mass of 12.6 kg (it’s a very heavy smiley face).

\[ F_{\text{Push}} = 36.2 \text{ N} \]

\[ F_g = \text{Weight} \]