1-Dimensional Motion: Inclined Plane

Guided Inquiry (GI)

Problem Statement

Kinematics is the study of the motion of objects. In the AP Physics curriculum, there are three primary kinematic equations. Two of the three kinematic equations will be derived in this experiment using motion data from a cart accelerating down an incline. Design and conduct an experiment that explores:

♦ Position and time for an accelerating object and then use of that relationship to derive a mathematical relationship between the two

♦ Velocity and time for an accelerating object and then use of that relationship to derive a mathematical relationship between the two

Materials and Equipment

For each student or group:
- Data collection system
- End stop
- Motion sensor
- Large base and support rod
- Dynamics track
- Dynamics track rod clamp
- Dynamics cart

Background

According to Newton’s first law, an object moving without the influence of a net external force maintains a constant velocity. The following equation is used to relate position and time mathematically for an object demonstrating constant velocity (zero acceleration):

\[ x = x_0 + vt \]  \hspace{1cm} (1)

where \( x \) is the position of the object at time \( t \) and \( x_0 \) is the initial position of the object.

However, an object that experiences a net external force does accelerate. In this lab, students will derive two of the fundamental kinematic equations involving motion with a constant acceleration.

Using Your Data Collection System

You may be using the following technical procedures in this activity. Your teacher will provide you with a copy of the instructions for these operations. If you are not familiar with a procedure, locate that operation in the list below. Use the tech tip number (identified by the number following the symbol: "\(*\)") to find the corresponding instructions.
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- Connecting a sensor to the data collection system \((1.2)\)
- Changing the sample rate \((5.1)\)
- Starting and stopping data recording \((6.2)\)
- Displaying data in a graph \((7.1.1)\)
- Displaying multiple graphs \((7.1.11)\)
- Finding the slope and intercept of a best-fit line \((9.6)\)
- Creating calculated data \((10.3)\)
- Saving your experiment \((11.1)\)

**Safety**

Follow all standard laboratory procedures

**Design and Conduct the Experiment**

Write a brief outline of the procedure you will use to collect data. Identify the steps in sequence and the points at which each piece of equipment will be used. Use the following questions to guide your experiment design.

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1. How will you setup the equipment so that the cart is subject to a constant acceleration when it rolls, and why is it important to use a constant acceleration when collecting data?

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2. What should be the proper sequence to start collecting data and to start the motion of the cart? Should they be done simultaneously?

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3. Hypothesize about the most advantageous initial velocity to use to help simplify your data analysis.

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4. The motion sensor and data collection system measure position versus time and velocity versus time simultaneously in 1-dimension. Where will you place the sensor to measure the cart's motion?

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5. Using position and time data, what variables should be graphed in order to produce a linear relationship between the two quantities? What axis should each be graphed on?

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6. What physical property does the slope of a position versus time graph represent?

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**Diagram of the Experiment**

Draw a diagram of the experimental setup you will use. Be sure to label each component and the measurements each component will be used to make. In the diagram, include components that were used but did not make any measurements.
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Relevant Equations

List the relevant equations you will use and show how you will use them in conjunction with your measured values to derive two kinematic equations: one relating position and time for an accelerating object, and the second relating velocity and time for an accelerating object.

Collect Data

Data Analysis

Present your data in the form of two graphs: one relating position to time, and the second relating velocity to time; and any other way you find useful to help derive two kinematic equations, one relating position and time for an accelerating object, and the second relating velocity and time for an accelerating object.

Analysis Questions

1. What is the physical meaning of the slope of your graph of velocity versus time for the cart traveling down an incline?

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2. What is the physical meaning of the vertical intercept of the graph?

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3. Compare the slope of your velocity versus time graph to the slope of the graphs from other groups. What factors affect whether or not your value is greater than or less than theirs?

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4. How does the slope of a velocity versus time graph compare to the slope of a position versus $t^2$ graph? What relationship exists between the two slopes?

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5. What is the physical meaning of the slope of the graph from Table 1 data?

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6. What is the physical meaning of the vertical intercept of the graph?

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7. Use your responses from the previous questions and other information from your data to derive a mathematical equation relating velocity $v$ at time $t$ to the acceleration $a$ experienced by the cart. Explain how you used your responses from the previous questions to derive this equation.

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8. Use your responses from the previous questions and other information from your data to derive a mathematical equation relating position $x$ at time $t$ to the acceleration $a$ experienced by the cart. Explain how you used your responses from the previous questions to derive this equation.

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Synthesis Questions

Use available resources to help you answer the following questions.

1. In the above analysis questions the following equations should have been derived:
   \[ x = x_0 + v_0 t + \frac{1}{2} at^2 \] and \[ v = v_0 + at \]. Do the versions you derived include a \( v_0 \) term, why or why not?

2. Another kinematic equation is: \[ x = \frac{1}{2} (v_0 + v)t \]. Use this equation in combination with one of the equations that you derived from this lab to derive a fourth equation:
   \[ v^2 = v_0^2 + 2ax \]

3. Write the 4 kinematic equations:

4. A bicyclist accelerates from rest at a rate of 4.0 m/s\(^2\). How far does he or she go after 5.0 seconds?
Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. What does the slope of a position versus time graph represent?
   - A. Acceleration
   - B. Velocity
   - C. Jerk
   - D. Momentum
   - E. Displacement

2. What does the slope of a velocity versus time graph represent?
   - A. Acceleration
   - B. Velocity
   - C. Jerk
   - D. Momentum
   - E. Displacement

3. What does the area of a velocity versus time graph represent?
   - A. Acceleration
   - B. Velocity
   - C. Jerk
   - D. Momentum
   - E. Displacement

4. What does the area of an acceleration versus time graph represent?
   - A. Acceleration
   - B. Change in Velocity
   - C. Jerk
   - D. Momentum
   - E. Displacement

5. A car accelerates uniformly from rest and covers 12 m in 2.0 seconds. What is the acceleration?
   - A. 48 m/s²
   - B. 10 m/s²
   - C. 24 m/s²
   - D. 6.0 m/s²
   - E. 0.5 m/s²
6. Starting from rest, a bus accelerates uniformly at a rate of $5 \text{ m/s}^2$ and reaches a velocity of $10 \text{ m/s}$. How much time did this take?

A. 50 s  
B. 10 s  
C. 2 s  
D. 4 s  
E. 0.5 s